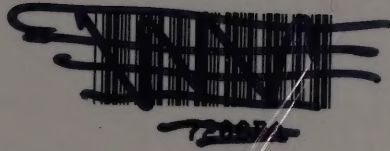




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BADGER CREEK CHANNEL DESIGN

November 1982

by

Bruce P. Van Haveren

William L. Jackson

Bureau of Land Management
 Division of Resource Systems
 Denver Service Center
 Denver, Colorado

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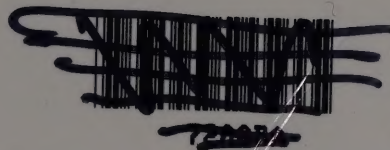
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BADGER CREEK CHANNEL DESIGN

INTRODUCTION

In March 1982, the Canon City District Hydrologist requested assistance from the Denver Service Center (D-470) on the Badger Creek Watershed Rehabilitation Plan. D-470 was asked to review in the field various options for rehabilitating disturbed portions of Badger Creek and the associated riparian and meadow complexes. In addition, it was agreed that D-470 would provide Canon City a stable stream channel design for those portions of Badger Creek selected for rehabilitation work. The purpose of this report is to present a stream channel design for Badger Creek.

BACKGROUND

Badger Creek is located approximately 10 miles northeast of Salida, Colorado, and is a tributary of the Arkansas River (Fig. 1). The Badger Creek watershed is 219.8 mi² and consists of steep slopes and generally shallow soils susceptible to rapid runoff during summer convectional storms. Average basin annual precipitation is 16.1 inches. Analysis of channel geometry and of short-term (2-year) stream gage data collected at two U.S. Geological Survey gaging stations (Fig. 1) suggest that annual peak discharges approximate 250-300 cfs and large, infrequent peak flows in excess of 10,000 cfs do occur. A large spring, located just upstream from the upper gaging station, contributes a fairly constant base flow of approximately 5 cfs. The year-round flows is one reason Badger Creek maintains a resident brown trout fishery.

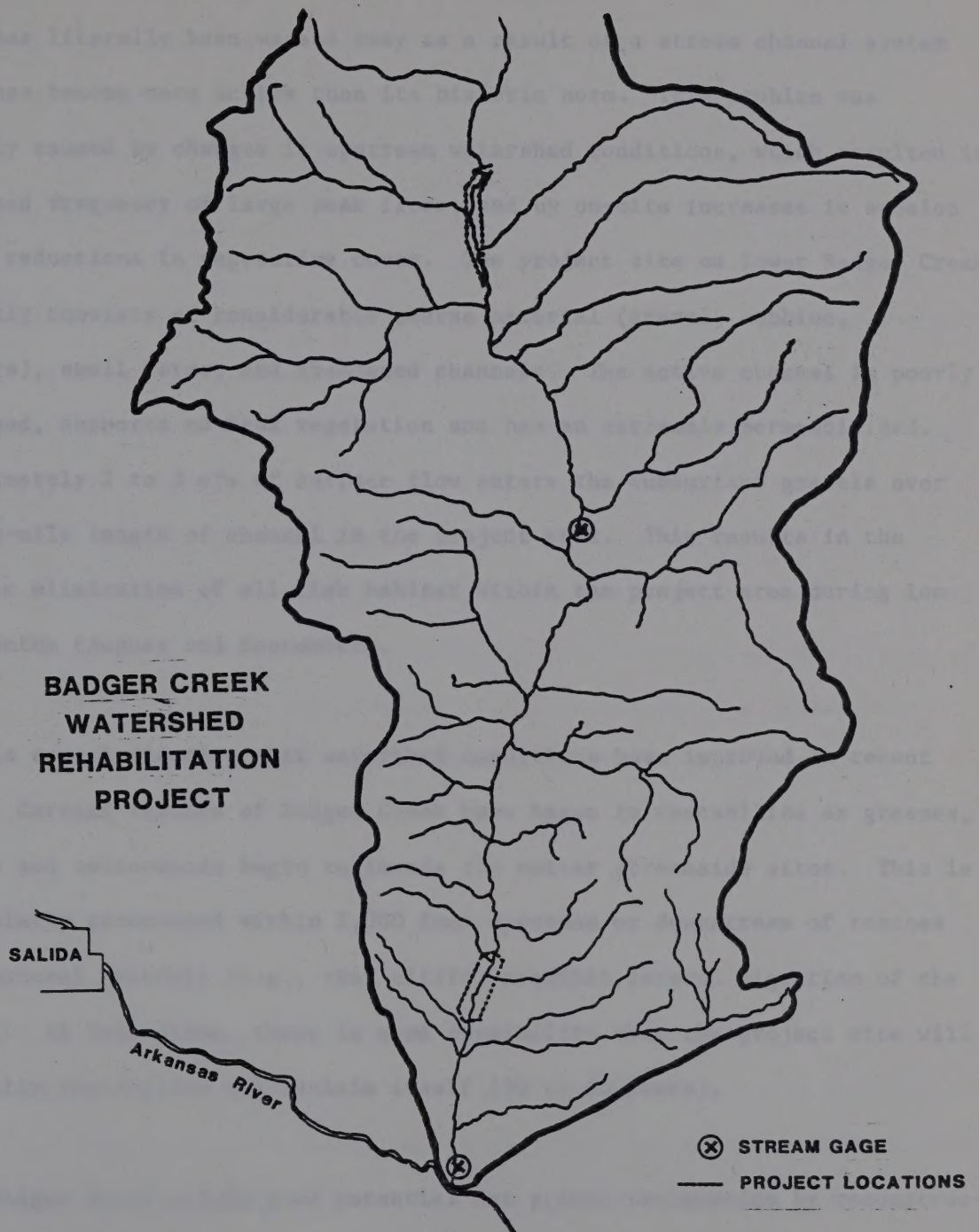


Figure 1: Badger Creek location map

The lower Badger Creek project area is located in a former alluvial meadow which has literally been washed away as a result of a stream channel system which has become more active than its historic norm. This problem was probably caused by changes in upstream watershed conditions, which resulted in increased frequency of large peak flows, and by on-site increases in erosion due to reductions in vegetative cover. The project site on lower Badger Creek presently consists of considerable coarse material (gravel, cobbles, boulders), small berms, and abandoned channels. The active channel is poorly developed, supports no bank vegetation and has an extremely permeable bed. Approximately 2 to 3 cfs of surface flow enters the subsurface gravels over the one-mile length of channel in the project area. This results in the periodic elimination of all fish habitat within the project area during low flow months (August and September).

There is some indication that watershed conditions have improved in recent years. Certain reaches of Badger Creek have begun to restabilize as grasses, willows and cottonwoods begin to invade the wetter streamside sites. This is particularly pronounced within 1,000 feet upstream or downstream of reaches where natural controls (e.g., rock cliffs) prohibit lateral migration of the channel. If left alone, there is some possibility that the project site will eventually restabilize and reclaim itself (30 to 50 years).

Lower Badger Creek offers good potential for prompt reclamation by reconstructing and restabilizing the channel and preparing a level, uniformly productive and moist upper flood plain. Benefits would be: 1) decreased channel erosion, 2) increased vegetative production, and 3) creation of one mile of

stream habitat suitable for fish spawning, rearing and migration. Project success is dependent upon upstream watershed conditions remaining stable or slowly improving.

DESIGN OBJECTIVES

The objective in the design of the channel for the disturbed meadow at Badger Creek is to maintain, as closely as possible, the geomorphic characteristics of the channel as measured in similar, more stable reaches and to make necessary modifications for sufficient bank stability to promote revegetation. It is hoped an incipient bed instability will be achieved at bankfull flows to allow both bed material load to be passed and some modification and evolution of the channel after increased bank stability due to revegetation. Gabion controls will be placed at approximately 1,000-ft intervals to reduce the tendency for lateral migration of the channel during extremely large discharges.

METHODS

Channel geometry data were collected in a downstream reach (Fig. 1) where the channel appeared to be functioning sufficiently under the present hydrologic regime (i.e., banks were vegetated and capacity was sufficient to handle the 1- to 2-year runoff event). Six cross sections (cross sections 1-6) were surveyed and a longitudinal profile was developed. A bed material size analysis was performed at each cross section. Width/depth ratios and median particle diameters were then plotted as a function of channel slope (Figs. 2 and 3). In addition, hydraulic data were calculated and summarized (Tables 1 and 2). Channel geometry data are included in Appendix III.

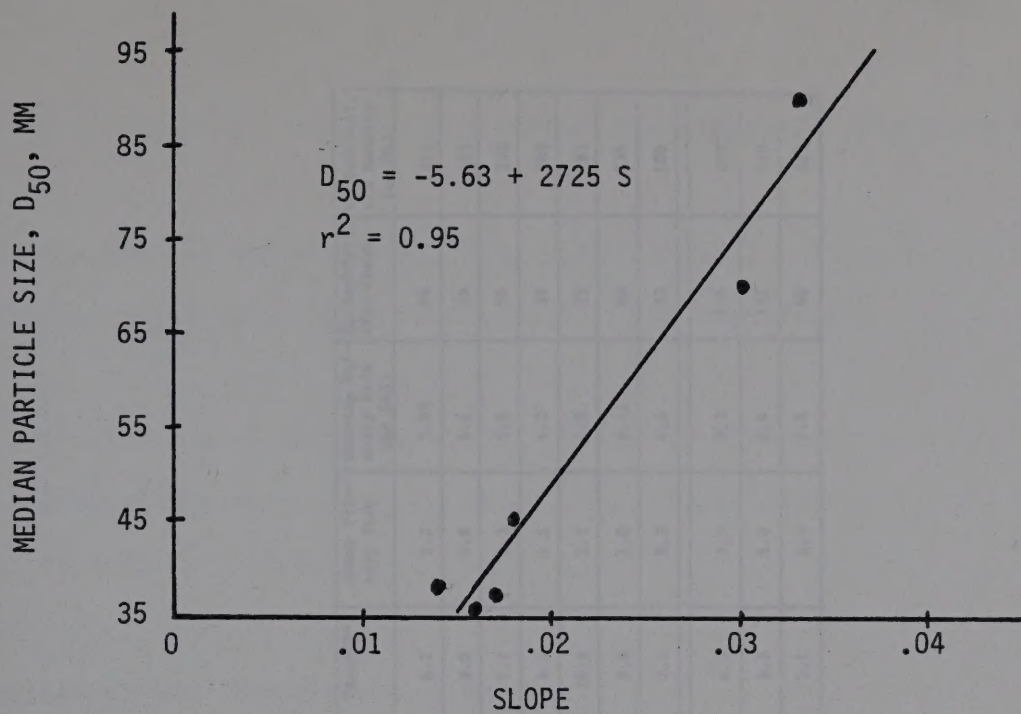


Figure 2. Median particle diameter of bed material versus slope: downstream stable channel reach.

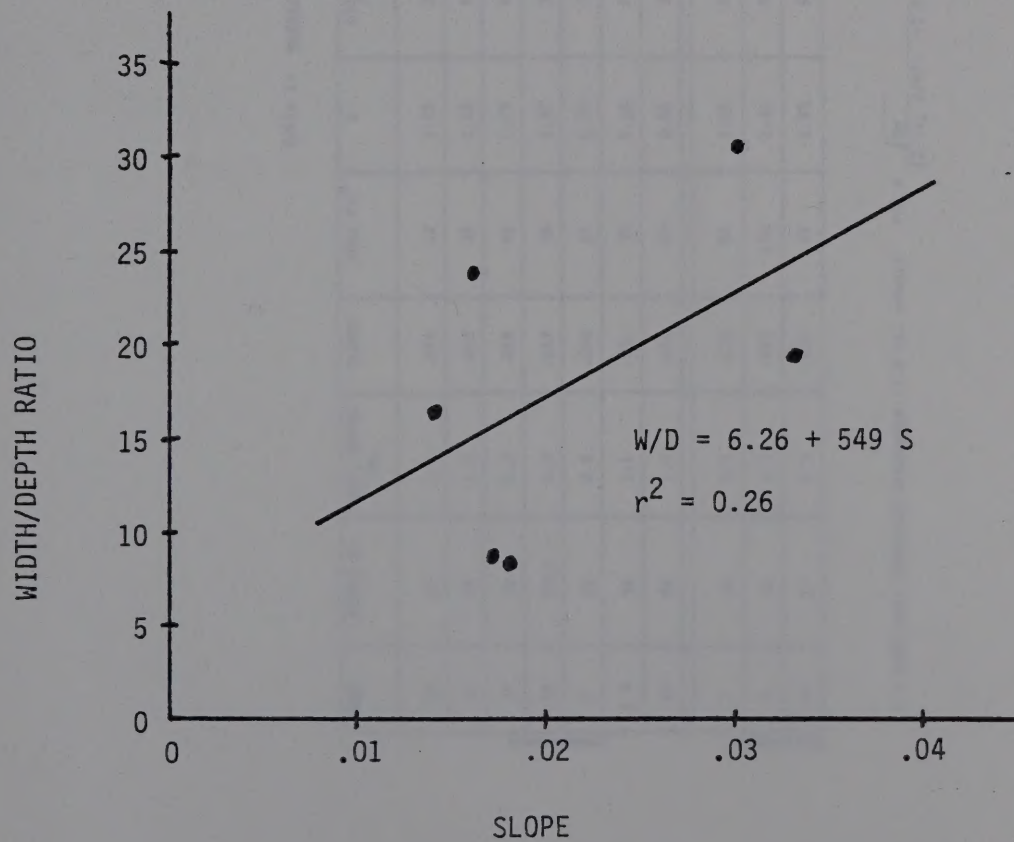


Figure 3. Width to depth ratio versus slope: downstream stable channel reach.

Table 1: Badger Creek Channel Data

	XSEC	WIDTH Ft.	AVG. DEPTH Ft.	SLOPE	AREA Ft. ²	R	D50 _{mm}	D84 _{mm}	ChezyC**	Chezy Velocity Ft/s	Manning Velocity Ft/s (n=.045)	Q, Bankfull, cfs, Chezy	Q, Bankfull, cfs Manning (n=.045)
Downstream	1*	26	1.6	.014	42	1.45	38	160	8.2	1.2	5.03	49	211
	2*	25	1.3	.033	32	1.15	90	160	9.0	1.8	6.6	56	211
	3*	19	2.2	.018	42	1.79	45	190	7.7	1.3	6.6	56	276
	4*	17.5	2.0	.017	35	1.62	37	120	6.7	1.1	6.0	39	209
	5	22	0.9	.030	19	0.79	70	160	10.9	1.7	4.9	32	93
	5 *	34	1.1	.03	39	1.10	70	160	9.8	1.8	6.11	69	238
	6*	24	1.0	.016	25	0.94	35	75	7.2	0.9	4.0	22	100
Disturbed	7	34	2.5	.028	84	2.16	50	110	6.0	1.5	9.3	124	780
	8	70	2.5	.010	174	2.31	80	140	6.5	1.0	5.8	172	110
	9*	17	2.5	.021	42	1.93	90	180	7.1	1.4	7.5	60	313

* = held est. bankfull discharge (1.8 yr. event) **C = $\frac{\sqrt{8g}}{[2 \log d/D84 + 1.0]}$

TABLE 2. BADGER CREEK SUMMARY DATA (BANKFULL CONDITIONS).

W/D average for all sections (1-6): 18.9 (S=8.3)

W/D average for sections 1, 2, 3, 4, 5b.: 16.8 (S=9.2)

Q: Average for all sections (1-6): 191cfs (S=13.8 cfs)

Q: Average for sections 1, 2, 3, 4, 5b.: 229cfs (S=29)

Q: Section 9: 313cfs

Overall slope: Downstream: 0.025

Project reach: 0.024

Drainage area at project reach: 196.2 mi²

A detailed longitudinal profile was then developed for the existing channel in the disturbed meadow. Three cross sections (cross sections 7-9) were measured to represent prereclamation conditions. Cross section 9 was selected because it appeared to represent a transition between oversized and undersized channel reaches in the disturbed meadow.

Utilizing the slope information from the disturbed meadow, Figures 2 and 3 were used to select initial channel dimensions. The hydraulic data from Tables 1 and 2 were averaged to serve as additional design criteria.

Hydraulic data from cross section 9 served as one check on design discharge. Conservative data selection was practiced to provide some factor of safety in the channel design.

Following the initial channel design, critical shear stress equations were used to check channel bed and bank stability. Because bank materials in the disturbed meadow are essentially noncohesive and unvegetated, it was expected that the initial channel design based upon the geomorphic criteria would have to be modified to allow for increased bank stability. Critical shear stress techniques were used to perform this modification. Geomorphic characteristics of the more natural (downstream) channel were maintained whenever possible.

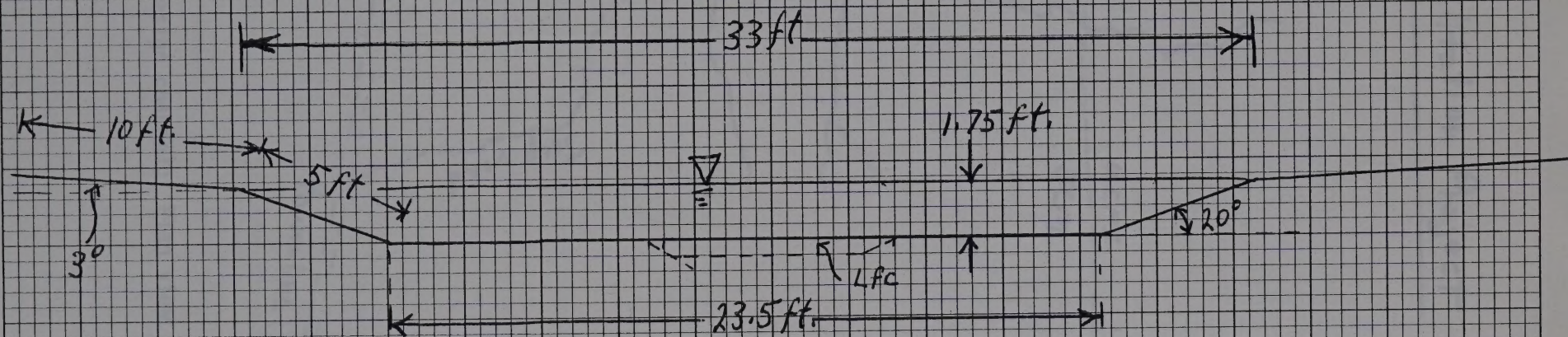
As a final design check, a second stable reach of channel located one mile upstream from the project site was selected for channel geometry measurements and a detailed analysis of bankfull discharge capacity.

CHANNEL DESIGN

The design channel has a trapezoidal cross section with a gently sloping upper flood plain. In Part 1 of Appendix I, a first approximation channel is designed using summary data from the channel geometry surveys. In Part 2 of Appendix I, the channel design is modified to provide for increased bank stability (second approximation) using hydraulic principles. The final design channel is shown in cross section in Figure 4 and in plan view in Figure 5.

For fisheries concerns, it may be desirable to construct a small, low flow channel (Fig. 4, part Lfc). However, such a channel can be expected to form naturally as the channel evolves during the first one to four years following construction. It is our best judgment that grasses will invade the lower banks and define a low flow channel one to two years after project completion which will result in a slight deepening of the channel center. The next step will be the invasion of willows and cottonwoods (2 to 4 years later) in the middle to upper portions of the channel banks, resulting in upper bank sediment deposition and another slight deepening of the channel. A successful project should result in a channel cross section comparable to that shown in Figure 6. Width/depth ratios will be reduced over time.

Figure 4: Design Channel: Disturbed Meadow,
Badger Creek, CO.



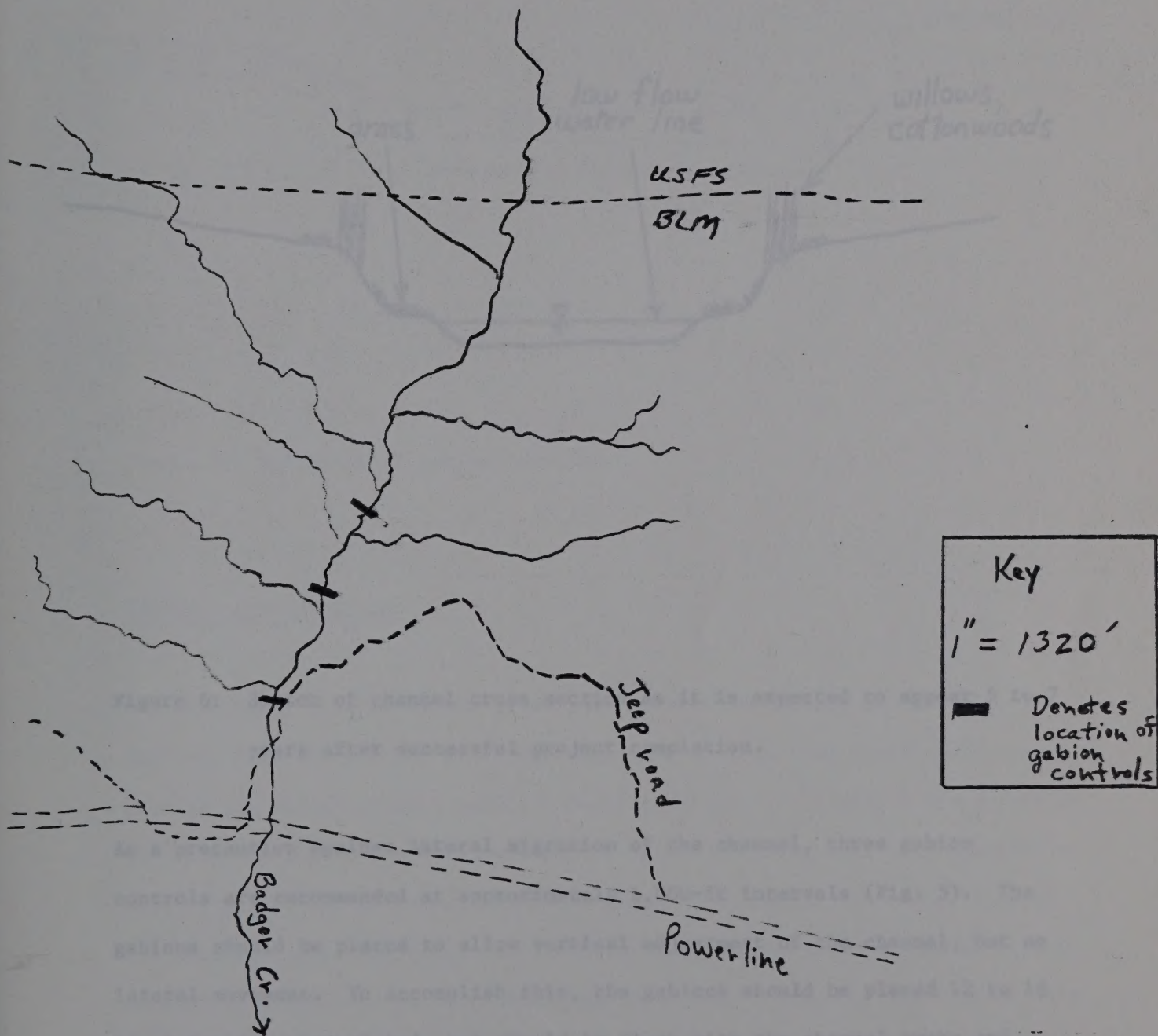
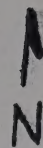
$$\begin{aligned}
 R_h &= 1.49 \\
 S &= .024 \\
 n &= .045 \\
 \text{Sinuosity} &= 1.2 - 1.3
 \end{aligned}$$

$$\begin{aligned}
 D_{16} &= 15 \text{ mm} \\
 D_{50} &= 60 \text{ mm} \\
 D_{84} &= 158 \text{ mm}
 \end{aligned}$$

$$\begin{aligned}
 V_{\text{bank full}} &= 6 \text{ fps} \\
 Q_{\text{bank full}} &= 335 \text{ cfs}
 \end{aligned}$$

5 ft.
scale

Badger Creek Rehabilitation Project



Key

1" = 1320'

 Denotes location of gabion controls

Figure 5: Design channel: Plan view

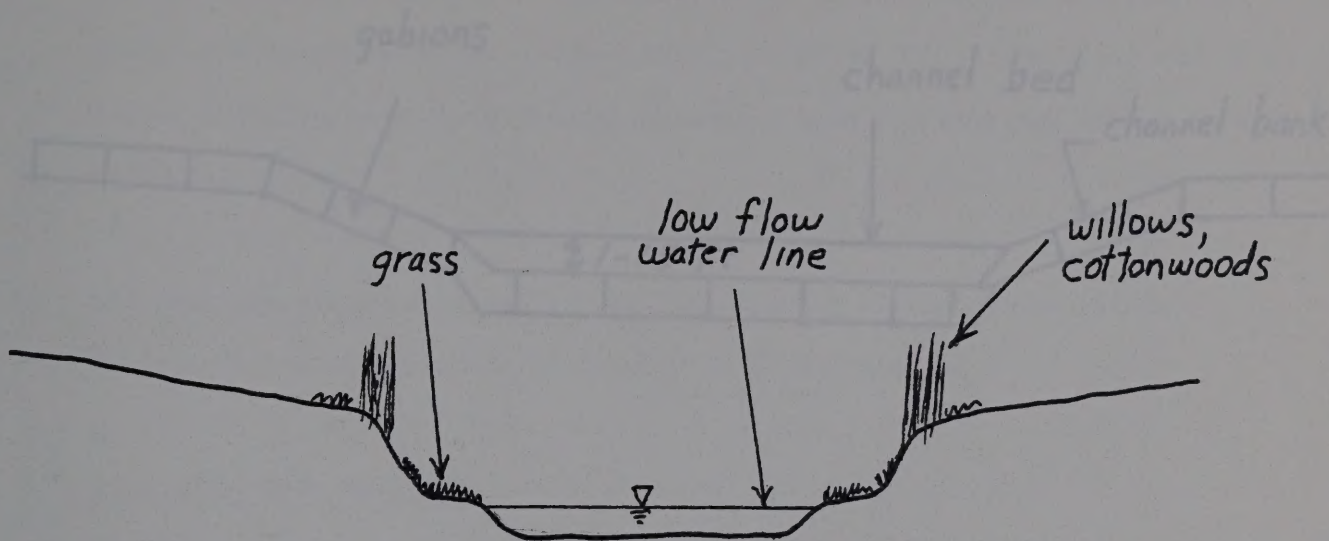


Figure 6: Sketch of channel cross section as it is expected to appear 5 to 7 years after successful project completion.

Figure 6: Sketch of channel cross section as it is expected to appear 5 to 7 years after successful project completion.

As a precaution against lateral migration of the channel, three gabion controls are recommended at approximately 1,000-ft intervals (Fig. 5). The gabions should be placed to allow vertical adjustment of the channel, but no lateral movement. To accomplish this, the gabions should be placed 12 to 18 in. below the channel bed, but should be flush with the channel banks and flood plain (Fig. 7). The wings should extend 30 ft beyond the upper edge of the channel bank on either side.

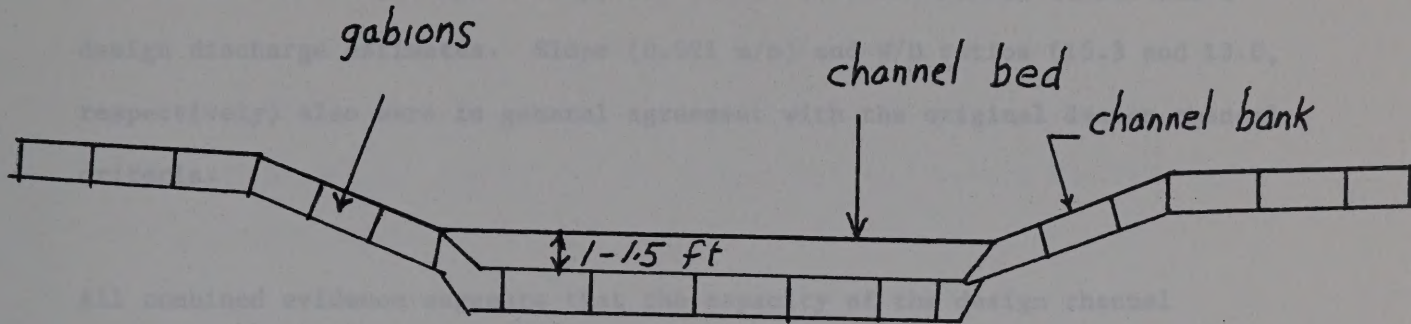


Figure 7: Placement of gabion controls.

CHANNEL CAPACITY CHECK

Two apparently stable reaches of channel, located approximately one mile upstream from the project site, were selected for detailed measurements to confirm the design channel bankfull capacity (Fig. 1). A single cross section was selected and surveyed in each reach. Bankfull elevations were measured at several points for approximately 100 m along each channel reach and included the selected cross sections. Bankfull and water surface elevations were then plotted as a function of distance along the channel (Appendix II). Lines were fitted to represent mean bankfull and water surface elevations. Mean bankfull capacity over each reach was then calculated.

The bankfull capacities for each cross section (cross sections 10 and 11) were 139 cfs and 207 cfs, respectively, and served to substantiate conservative design discharge estimates. Slope (0.021 m/m) and W/D ratios (15.3 and 13.0, respectively) also were in general agreement with the original design channel criteria.

All combined evidence suggests that the capacity of the design channel includes a factor of safety of from 30 to 60 percent.

HYDROLOGIC RISK ANALYSIS

An important question facing the designer of any hydrologic project is: what is the risk of failure? The cost of failure is equal to the actual project cost plus the costs of repair or reconstruction. (There may also be less tangible costs related to political and/or environmental consequences of failure.) With these costs in mind, the land manager will want to know the risk or probability of project failure. The stable channel design given in Figure 4 is based on a design flow of 335 cfs (bankfull discharge with a 60% safety factor built in). We estimate the return period of this flow to be approximately 2 years. The reconstructed channel is designed to withstand the 2-year return flow regardless of the number of events. The major concern is for flows having a return period of between 5 and 20 years. (Flows with return periods greater than 20 years have less than 10% chance of occurring in the first 2 years of project life.) The 5-year flood has a 36% chance of being equalled or exceeded in the first 2 years. This represents a high risk, since the 5-year flood (approx. 1,900 cfs) could do considerable damage to the

new channel. With the installation of the gabion controls, we feel the channel could withstand one such flood event without serious consequences. The 10-year flood (approx. 3,800 cfs) has a 19% chance of occurring at least once in the first 2 years. Again, the gabion controls would probably prevent destruction of the new channel by the 10-year flood, lowering the risk of total project failure.

We feel the design channel, together with the gabion controls, represents a reasonable compromise between excessive project costs and high risk of failure. After the initial 2 years, the channel stability will gradually increase as vegetation invades the banks and flood plain. The channel will evolve over time into a slightly narrower and deeper configuration. With this evolution towards greater stability, the risk of project failure decreases with time.

MONITORING

We recommend that a project monitoring plan be implemented for the project reach on Badger Creek. The plan should include the following minimum procedures:

- (1) Permanently located stream cross sections for collecting channel geometry, hydraulic, and bed material size information.
- (2) Crest-stage gages at the top and bottom of project reach for determining peak discharges.

(3) Permanently located photo points for "before and after" photographs.

(4) Vegetation transects to monitor revegetation success and evolution of riparian species composition.

All four procedures are inexpensive, effective methods of monitoring the success of the project and will provide useful data for future projects of a similar nature.

SUMMARY AND FURTHER RECOMMENDATIONS

A stable channel design was developed for the disturbed reach of Badger Creek above the powerline. The design was based on stable channel reaches located above and below the project area. The design channel (Fig. 4) is based on a bankfull discharge plus a 60% safety factor or a design flow of 335 cfs.

Three gabion control structures, spaced at approximately 1,000-ft intervals in the project reach, should be installed to prevent lateral channel migration. This approach should result in a "risk of failure" factor of less than 10% for the first 2 years. Channel gradient and sinuosity will not be altered significantly from the present situation. When the intensive plane-table survey is completed by the District, we will superimpose the stream channel design on the plane-table map.

We did not consider the extreme flood flows in our channel design. The upper banks of the design channel have a 3° slope, based on our best judgment; this has not been validated with any field data. We propose to spend 2 to 3 days at Badger Creek next spring to develop a flood plain design for the project

area. As with the stable channel design, the design flood plain would be superimposed on the plane-table map. Upon completion of that task, the District could then draw up the revegetation plan, thus completing the necessary pre-project planning.

APPENDIX I

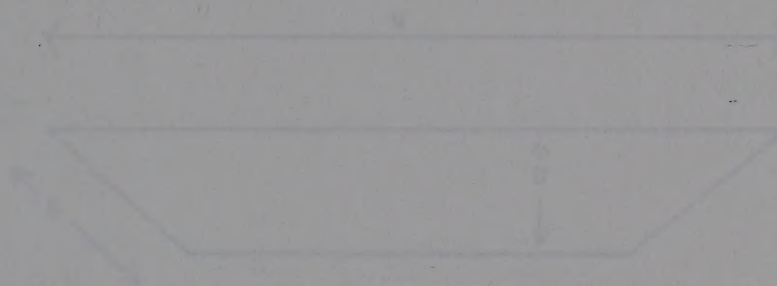
Channel Design Calculations

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APPENDIX I: Channel Design Calculations

Table 1: Geomorphic/Hydrologic First Approximation

Channel Design Flow	1	500 cfs
Velocity	2	1.5 ft/s
H/S ratio	3	1.5 ft/s
Q ₅₀	4	60 mm (increasing smaller)
Slope	5	0.024 ft/ft
Manning "n"	6	0.045 (Chow, 1959)
Velocity	7	5 fpm
Area	8	36 ft ²
Shape	9	Trapezoidal



APPENDIX I

Design channel, definition sketch

Area = $W \pm D$ - Channel Design Calculations

where $D = D/\tan$

$D = 1.5 D$

Therefore:

$A = 1.5 W \pm D^2/\tan$

where $\tan$ is selected to be less than the

value (Craf, 1971, Fig. 4-19,

angle of repose = 35°-38°

= 35°

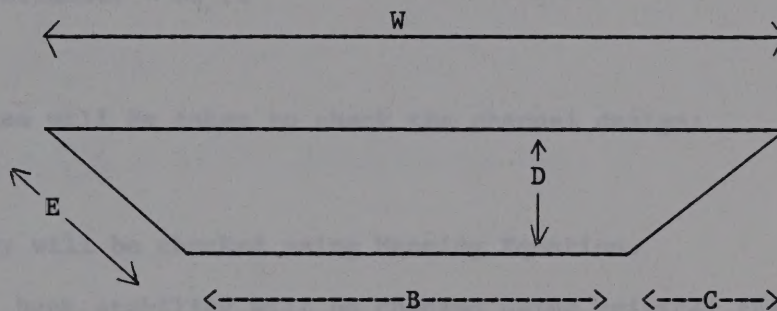
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* Rounded up to incorporate some safety factor.
** "D" in this equation is defined as above and differs from "average D" used in the calculation of H/S ratio from channel geometry data. This provides a conservative (or over-size) channel design.

APPENDIX I: Channel Design Calculations

Part 1. Geomorphic/Hydrologic First Approximation

Channel Design Flow*	:	300 cfs
Sinuosity	:	1.3 ft/ft
W/D ratio	:	19 ft/ft
D ₅₀	:	60 mm (becoming smaller)
Slope	:	.024 ft/ft
Manning "n"	:	.045 (Chow, 1959)
Velocity	:	6 fps
Area	:	50 ft ²
Shape	:	Trapezoidal



Design channel, definition sketch

$$\text{Area} = W \times D - 2(1/2 C \times D) \quad (1)^{**}$$

$$\text{where } C = D/\tan \quad (2)$$

$$W = 19 D \quad (3)$$

Therefore:

$$A = 19 D^2 - D^2/\tan \quad (4)$$

where is selected to be less than the angle of

repose (Graf, 1971, Fig. 6.19, p. 115)

angle of repose = 36°-38°

= 30°

* Rounded up to incorporate some safety factor.

** "D" in this equation is defined as shown and differs from "average D" used in the calculation of W/D ratios from downstream channel geometry data. This provides a conservative (or over-sized) channel design.

Therefore:

$$A = 19 D^2 - 1.72 D^2 = 17.28 D^2$$

$$D = \sqrt{A/17.28} = 1.7 \text{ ft}$$

$$W = 19 D = 32 \text{ ft}$$

$$B = W - 2(C) = W - 2(3) = 26 \text{ ft}$$

$$\theta = 30^\circ$$

$$E = 3.4$$

$$\text{Hydraulic Radius} = 1.52$$

$$\text{Wetted Perimeter} = 33 \text{ ft}$$

Two approaches will be taken to check the channel design:

- 1.) Capacity will be checked using Manning Equation.
- 2.) Bed and bank stability will be checked using critical shear stress equation.

Capacity Check:

$$Q = A \frac{1.49}{n} R^{2/3} S^{1/2} \quad (5)$$

$$Q = 50 \times \frac{1.49}{.045} (1.52)^{2/3} (.024)^{1/2}$$

$$Q = 339 \text{ cfs} \quad \text{--- a little high, but not bad}$$

Stability Check:

- 1.) Bed (assuming stable banks)

$$D_{50} = 60 \text{ mm}$$

$$(\tau_0)_c = 1.0 \text{ lb/ft}^2 \quad (\text{Lane, 1953})$$

$$= 5,000 \text{ g/m}^2$$

$$\tau_0 = \gamma S R_h \quad (6)$$

$$\therefore R_h = \frac{5\text{kg}}{(.024)(1000)} \approx .21\text{m} \approx .7 \text{ ft}$$

$$V = \frac{1.49}{.045} (.7)^{2/3} (.024)^{1/2}$$

$$V = 4.04$$

$$Q = 300 \text{ cfs}$$

$$\therefore A = 74.2 \text{ ft}^2 \quad \begin{array}{l} \text{indicates on unstable bed} \\ \text{suggests larger area/lower velocity} \end{array}$$

If we assume the effective particle size is larger than D_{50} (eg. D_{85}):

R_h in the above calculation becomes

$$\frac{10 \text{ kg}}{(.024)(1000)} = 1.4 \text{ ft}$$

$$V = \frac{1.49}{.045} (1.4)^{2/3} (.024)^{1/2} = 6.4 \text{ fps}$$

$$Q = 300 \text{ cfs}$$

$$\therefore A = 47 \text{ ft}^2 \quad \text{--- This is a good check.}$$

For an additional check, use critical velocity approach after Hjulstrom (1935).

The Hjulstrom curve (Graff, 1971, Fig. 6.2) indicates that for $D = 60\text{mm}$, the critical mean velocity is 6.6 ft/s. Thus, the bed is stable by this criterion too.

Thus, the design channel bed appears stable—just. This is the ideal condition as natural alluvial channel beds need to become mobile at $Q >$ bankfull (approximately).

2.) Bank:

$$\theta = 30^\circ$$

$$\alpha \text{ repose} = 38^\circ \quad (\text{without vegetation})$$

$$\begin{aligned} \frac{(\tau_0 \text{ bank})_{cr}}{(\tau_0 \text{ bed})_{cr}} &= \cos\theta \sqrt{1 - \frac{\tan^2\theta}{\tan^2\alpha}} & (7) \\ &= .87 \quad .46 \quad = .59 \end{aligned}$$

$$\tau_0 \text{ Bed} = 10 \text{ kg/m}^2$$

$$\therefore (\tau_0 \text{ Bank})_{cr} = 5.9 \text{ kg/m}^2$$

$$(\tau_0 \text{ Bank})_{cr} = 0.75 \gamma \text{ SD} \quad (8)$$

$$\therefore D = \frac{5.9 \text{ kg/m}^2}{(.75)(1000)(.024)} = 1.08 \text{ ft}$$

The banks are unstable under the above conditions.

Part 2. Second Approximation: Based Upon Hydraulic Principles

The channel design based upon geomorphic data collected downstream of the disturbed meadow is predicted to have, as expected, unstable banks in the first several years after construction (unvegetated condition). The initial approximation will be modified to include slightly less steep channel banks. Geomorphic criteria from Part I will be maintained where possible.

$$\text{Set } \theta = 20^\circ$$

Substituting into Equation (4), keeping $A = 50 \text{ ft}^2$, and solving for D:

$$A = 19 D^2 - D^2/\tan \theta \quad (4)$$

$$= 19 D^2 - 2.75 D^2$$

$$\therefore D = \sqrt{A/16.25} = 1.75 \text{ ft}$$

$$W = 19 D = 33 \text{ ft}$$

$$B = W - 2(C) = W - 2(D/\tan \theta) \cong 23.5 \text{ ft}$$

$$= 20^\circ$$

$$E \cong 5 \text{ ft}$$

$$R_h = 1.49$$

Capacity and bed stability are essentially unaffected by the modification.

Bank Stability Check (Second Approximation):

$$\theta = 20^\circ$$

$$\alpha \text{ repose} = 38^\circ \text{ (unvegetated)}$$

$$\frac{(\tau_0 \text{ bank})_{cr}}{(\tau_0 \text{ bed})_{cr}} = \cos \theta \sqrt{1 - \frac{\tan^2 \theta}{\tan^2 \alpha}} \quad (7)$$

$$= .94 \quad .78 \quad = .83$$

$$\text{Given } \tau_0 \text{ bed} = 10 \text{ kg/m}^2, \text{ then}$$

$$(\tau_0 \text{ bank})_{cr} = 7.3 \text{ kg/m}^2$$

$$= 0.75 \gamma SD \quad (8)$$

$$\therefore D = \frac{8.3 (3.28 \text{ ft/m})}{(.75)(1000)(.024)} = 1.5 \text{ ft}$$

This is acceptably close to the 1.75 ft modified design depth.

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Chow, V.T. 1959. Open channel hydraulics. McGraw-Hill Book Co. New York.

Graf, W.H. 1971. Hydraulics of sediment transport. McGraw-Hill Book Co., New York, N.Y. 513p.

APPENDIX II

Design Capacity Check

APPENDIX II

Design Capacity Check

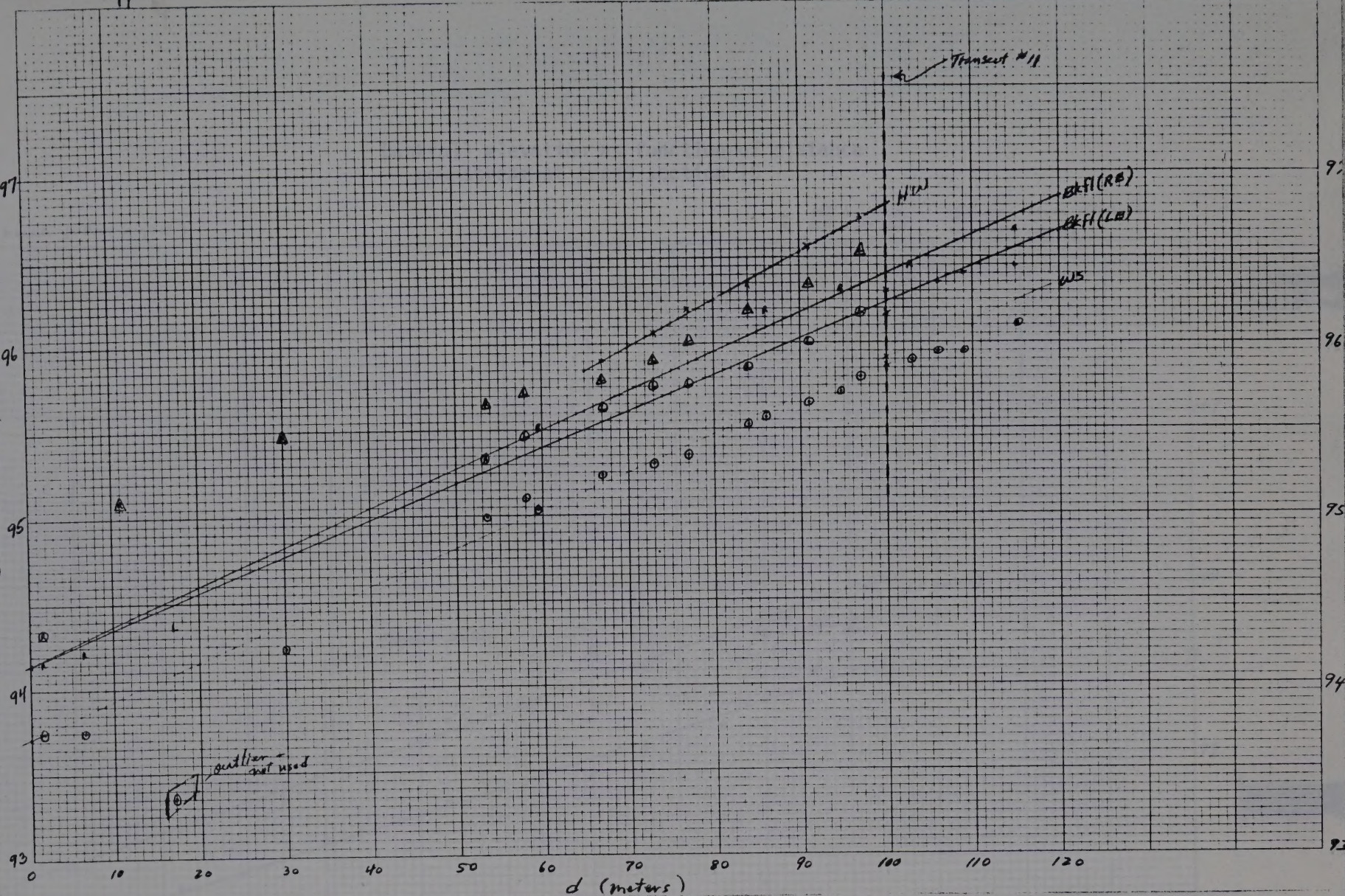
Upper Reach (above project)

(x) Upper terrace RE (x) High water L Bkfl RE (L) lower terrace LE
 (o) Water surface (R) Lower terrace RE R Bkfl RE (R) upper terrace LE

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Elevation (meters)

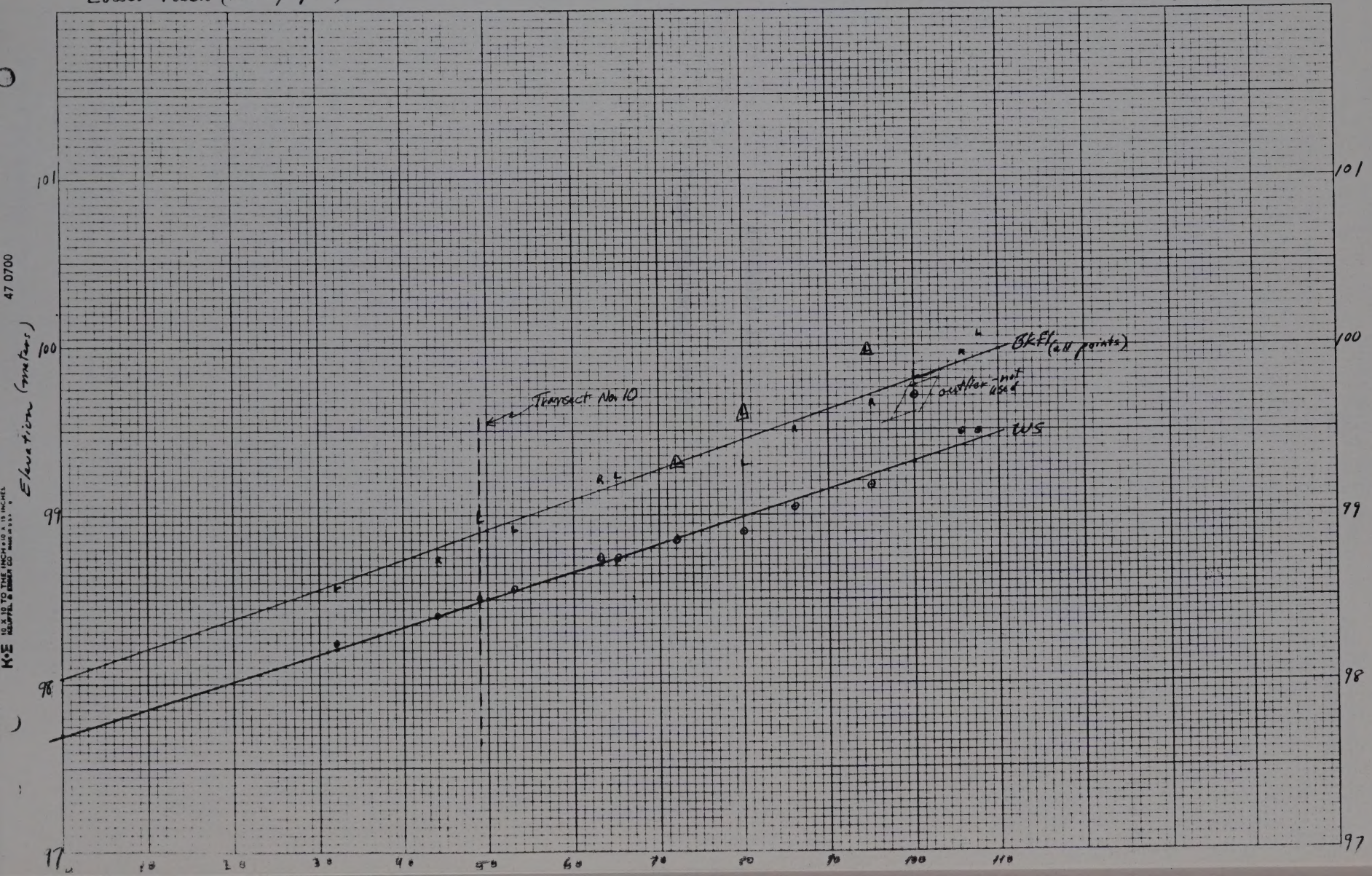


Bankfull Elevation as function of distance downstream at cross-section 11

Bankfull elevation as function of distance downstream at cross-section 10

Lower reach (above project)

L BLF left bank
R BLF right bank
△ upper terrace left bank
○ water surface

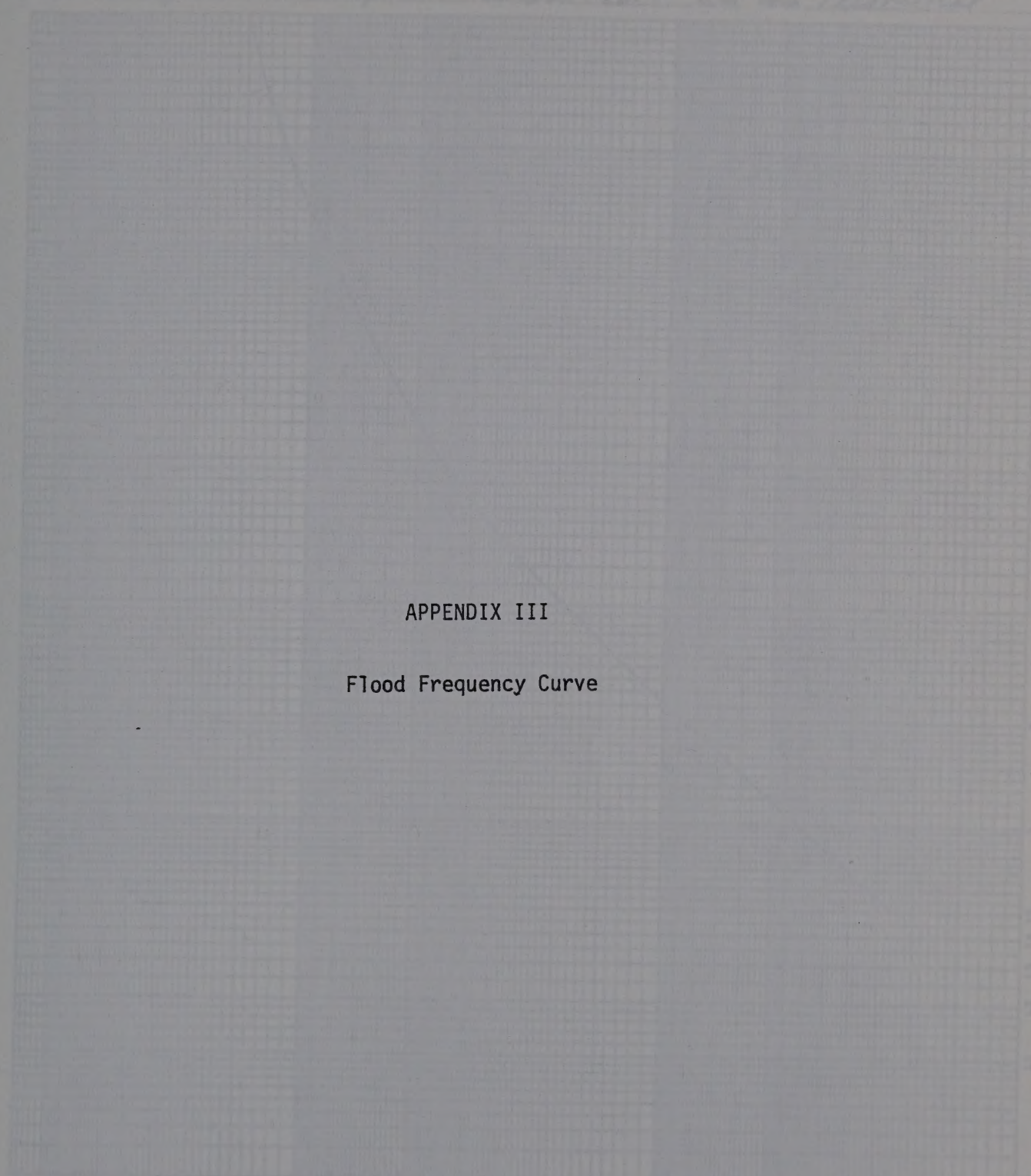


Magazine and frequency of *Budger Creek at project end*
based on regional rain frequency *season 1967-1968* *Thermal*

APPENDIX III

Flood Frequency Curve

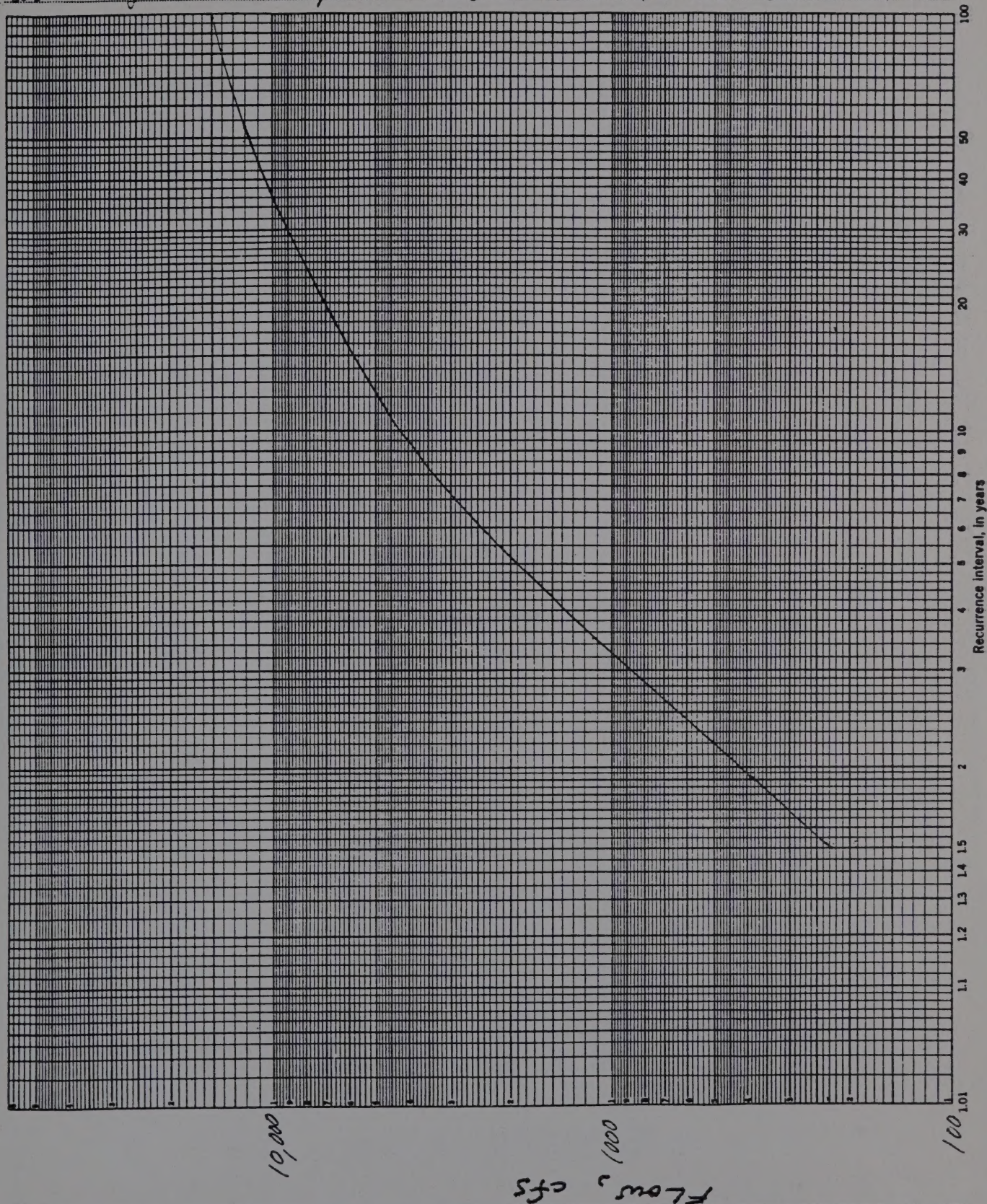
Budger Creek at Project End



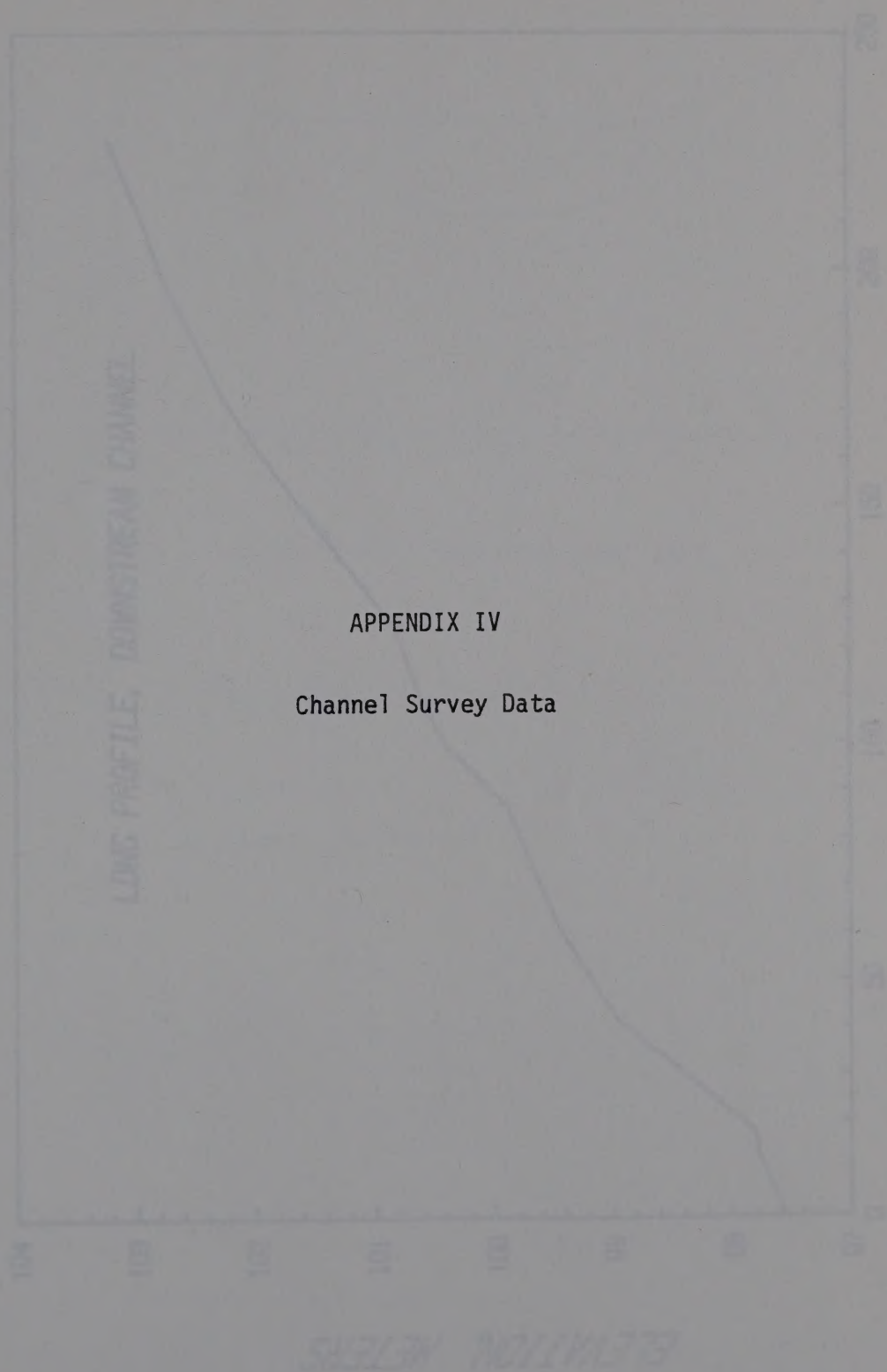
549 1-07-68

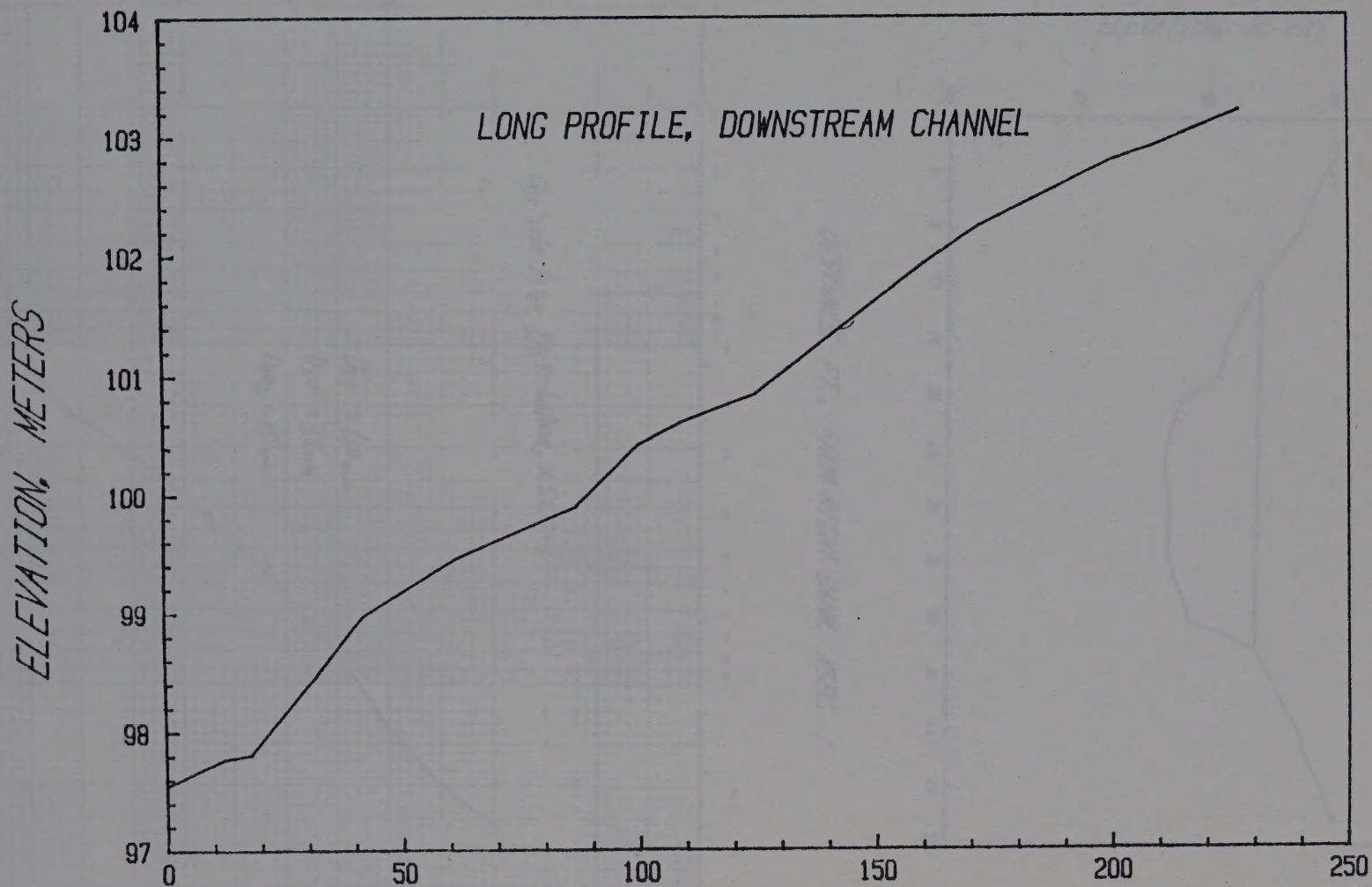
Magnitude and frequency of Badger Creek at project reach on
(based on regional relationships) Drainage area 196.2 sq. mi. Period Theoretical

Badger Creek at Project Reach

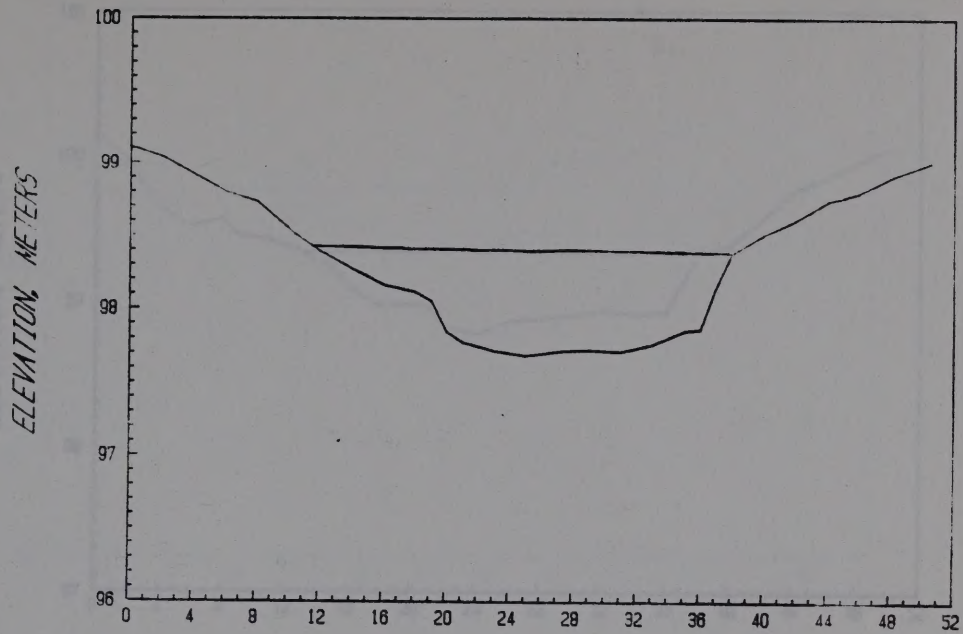


Sheet No. _____ of _____ Sheets. Prepared by _____ Date _____ Checked by _____

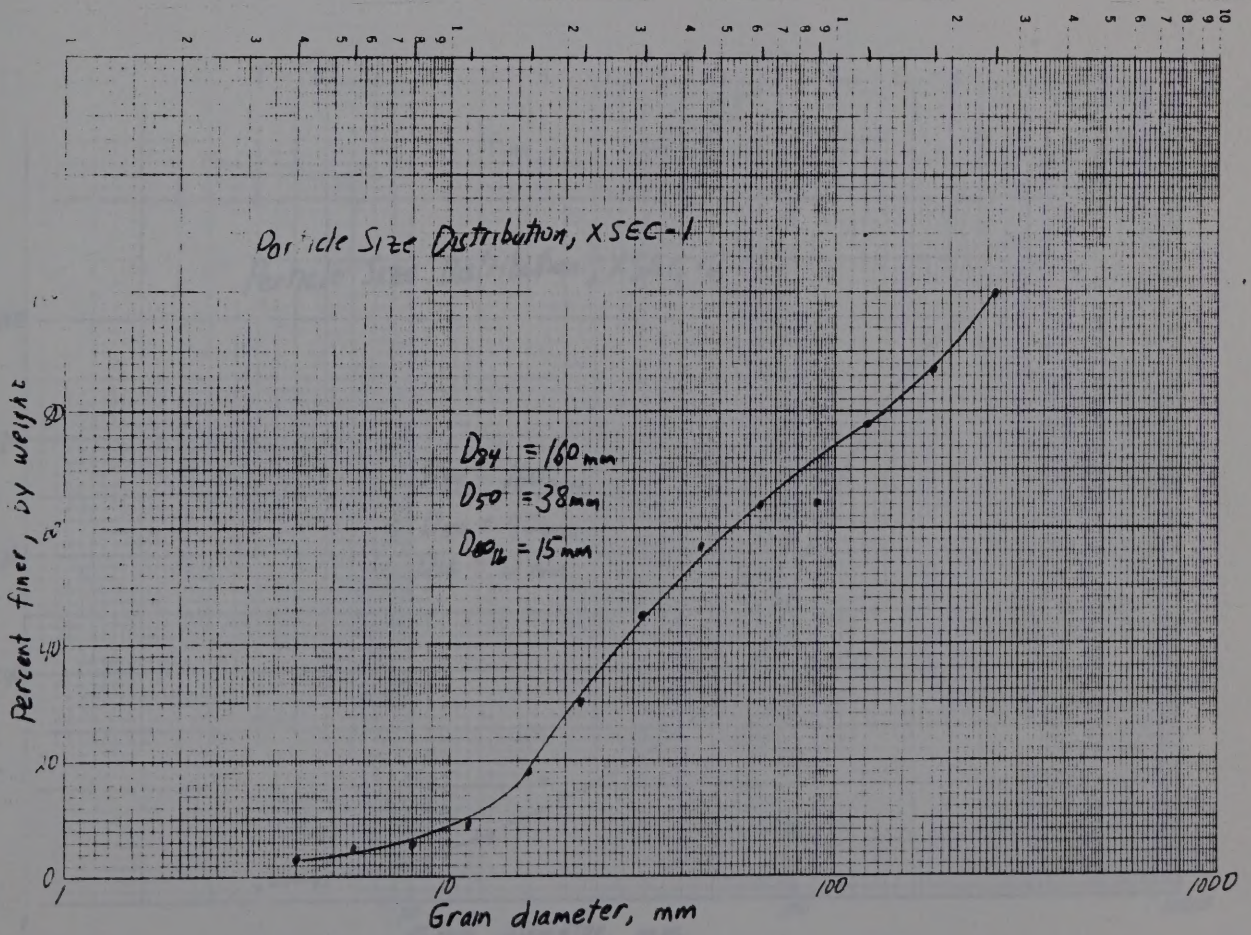


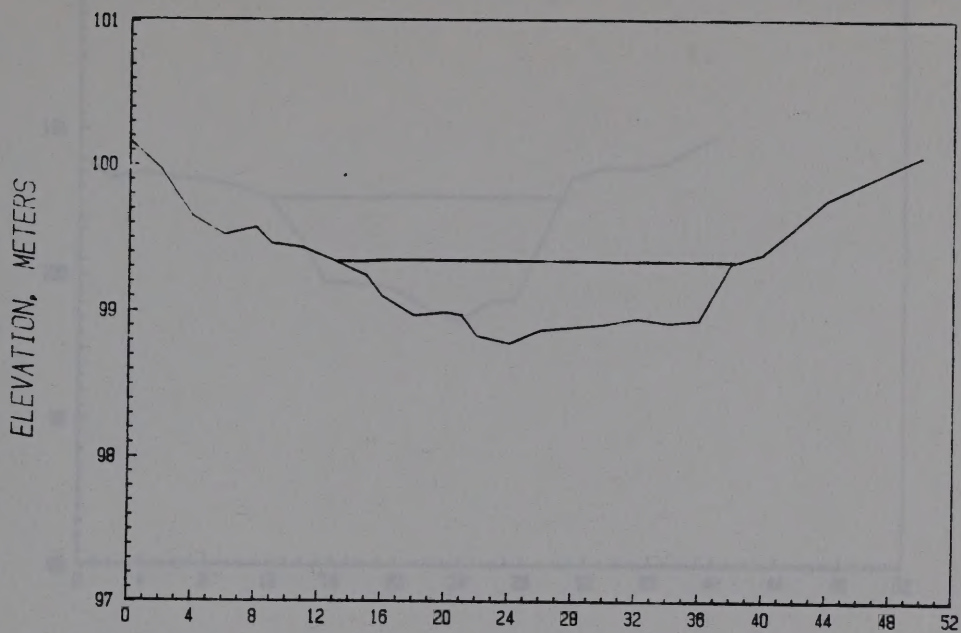


DISTANCE, M., FROM DOWNSTREAM MARKER

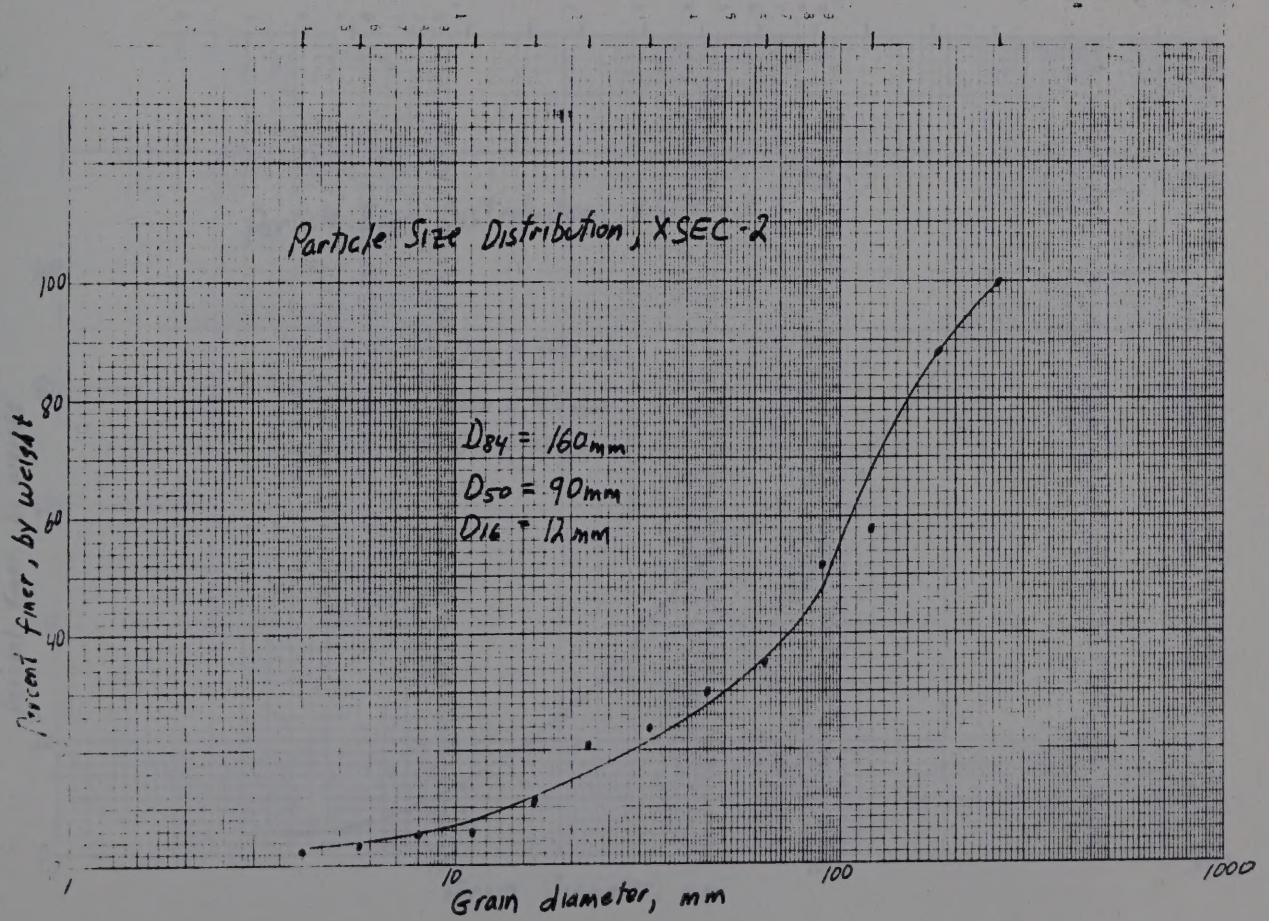


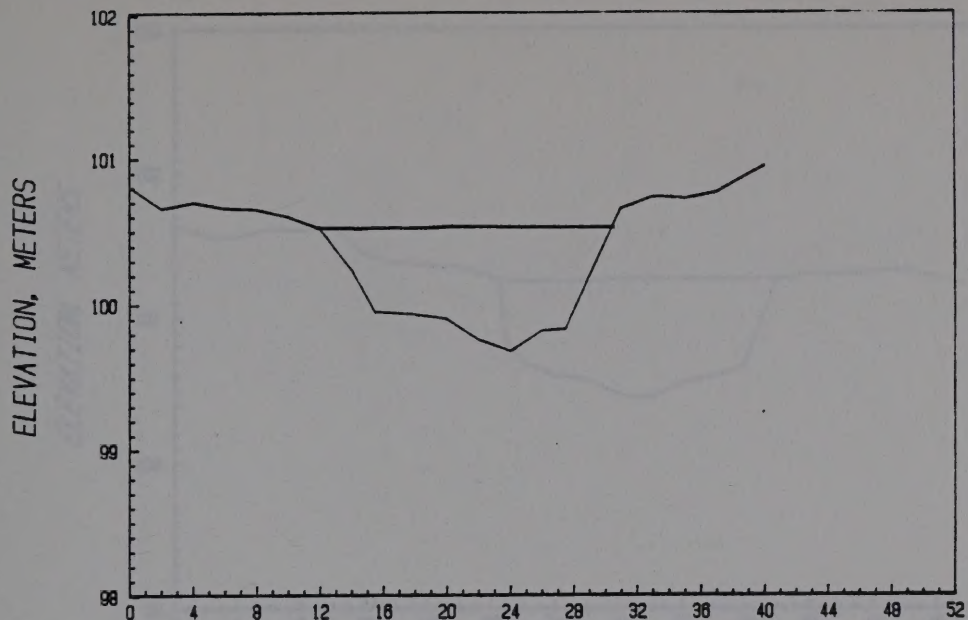
DISTANCE, FT., FROM RIGHT BANK, XSEC. 1



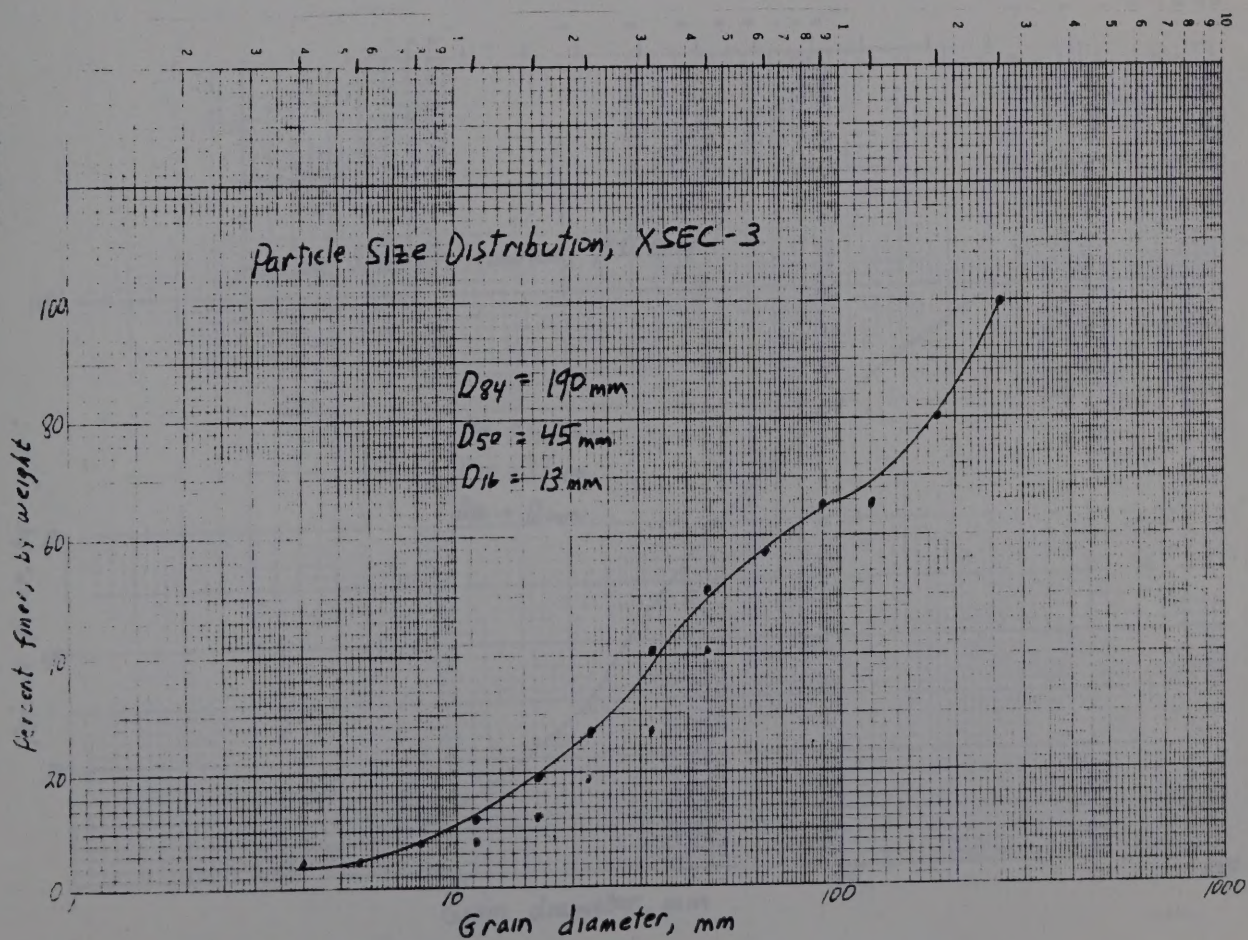


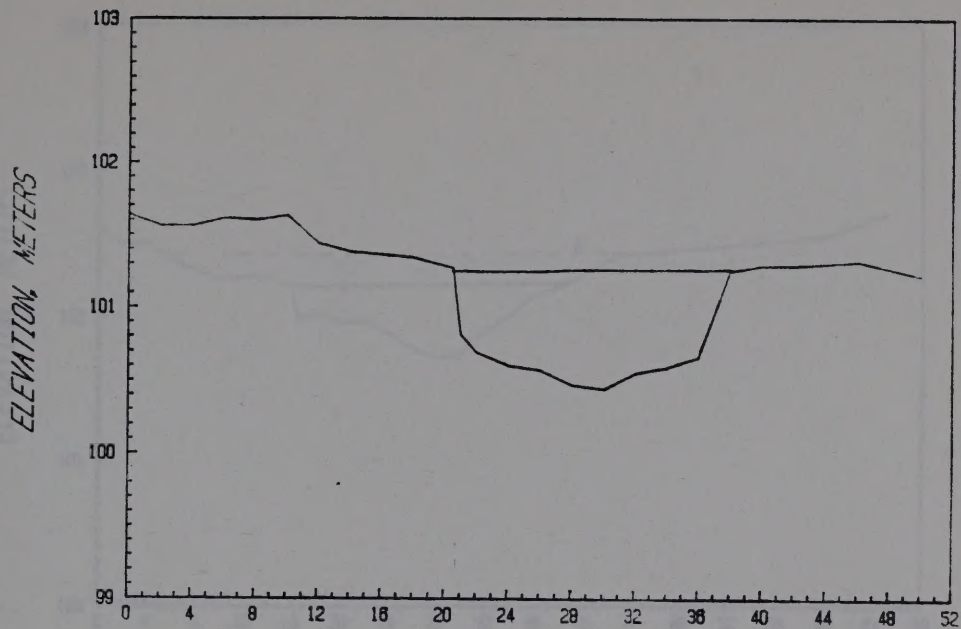
DISTANCE, FT., FROM RIGHT BANK, XSEC. 2



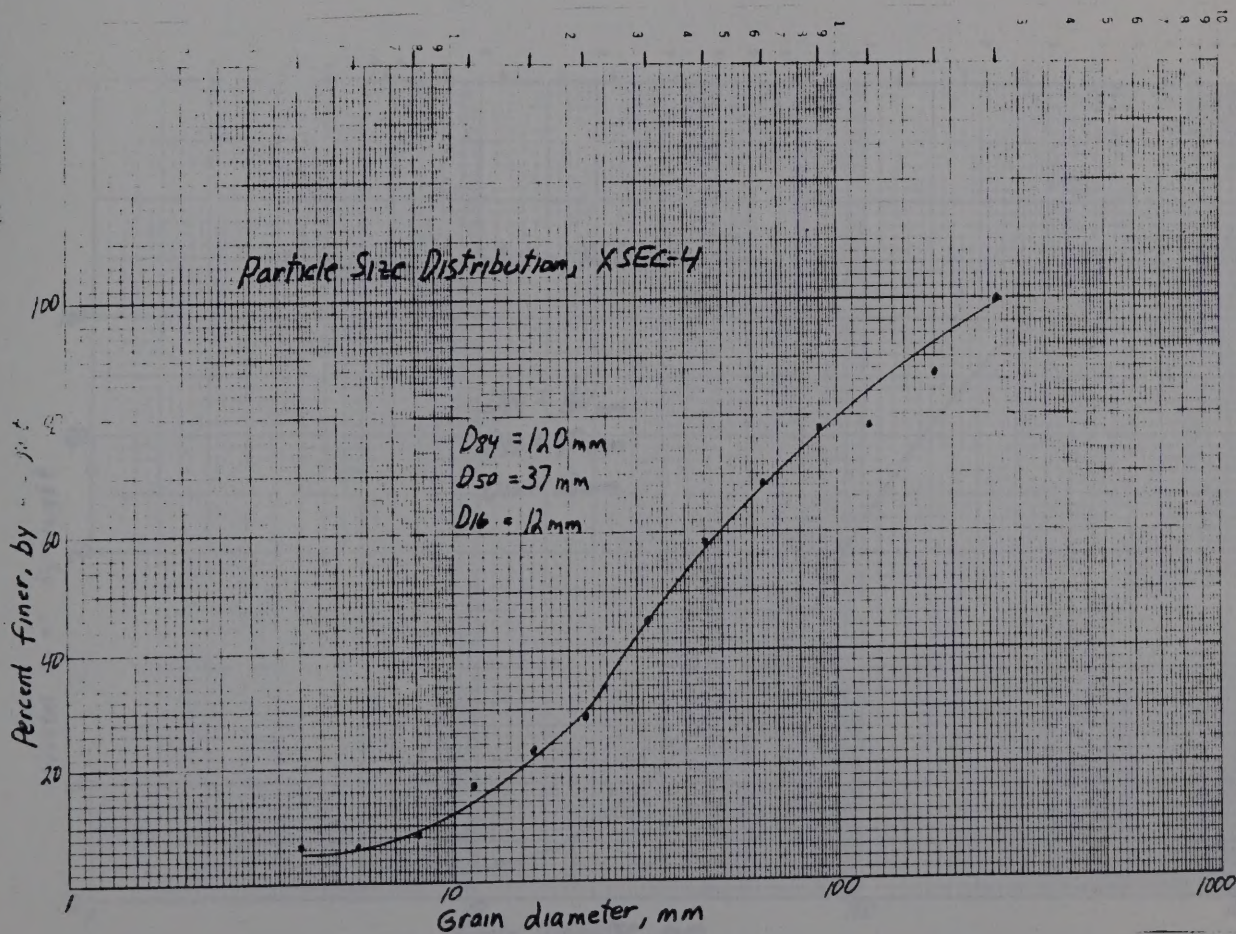


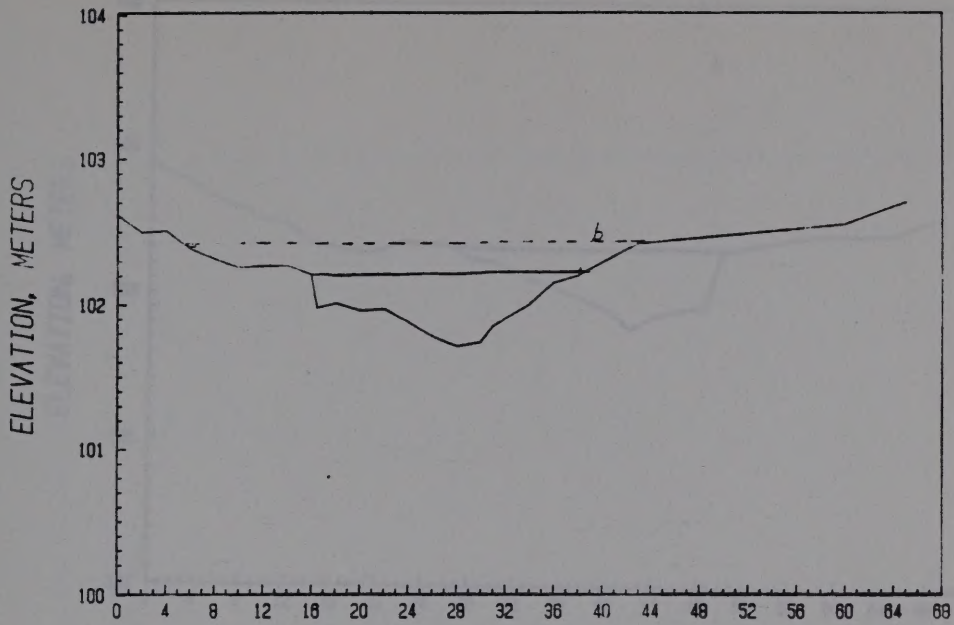
DISTANCE, FT., FROM RIGHT BANK, XSEC. 3



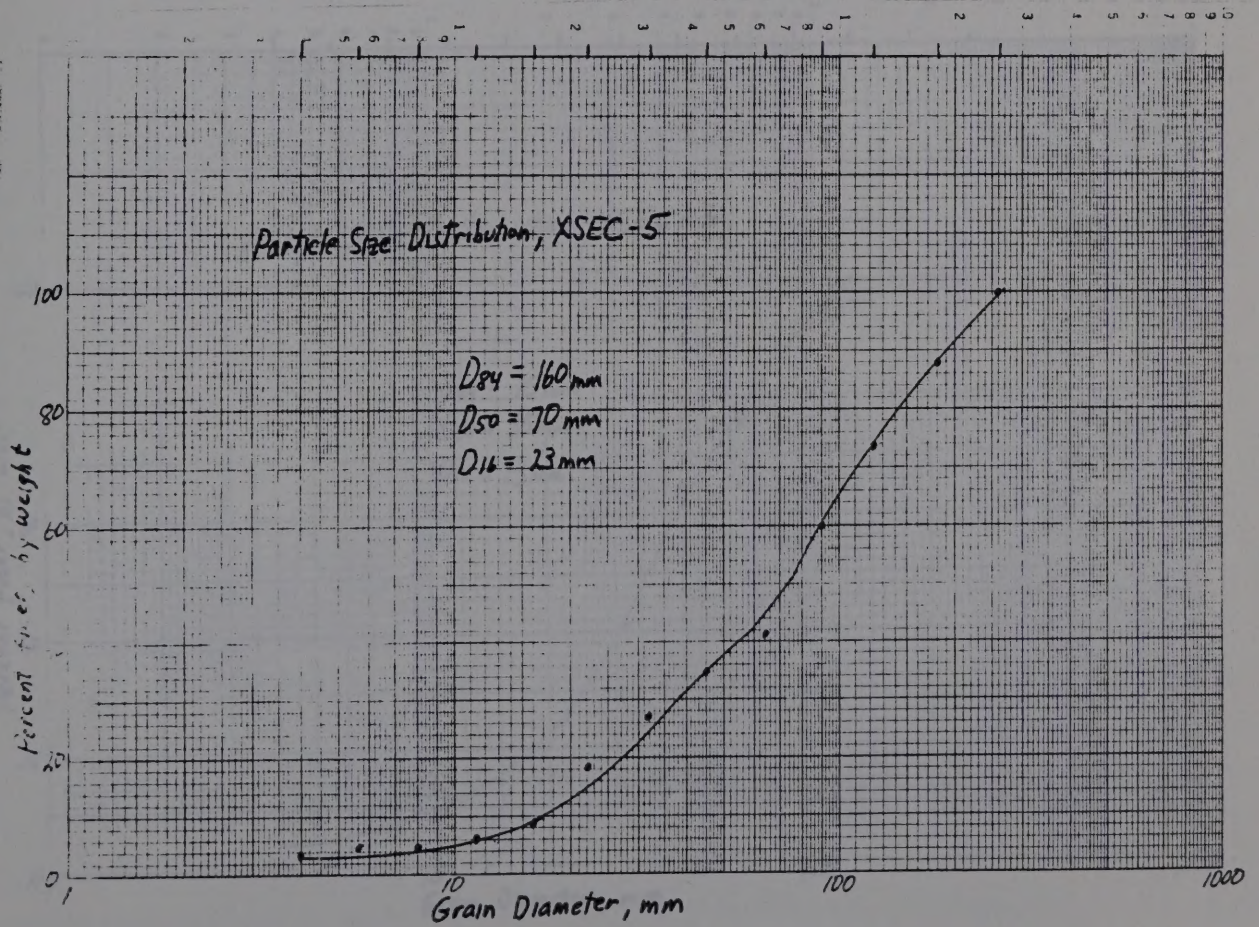


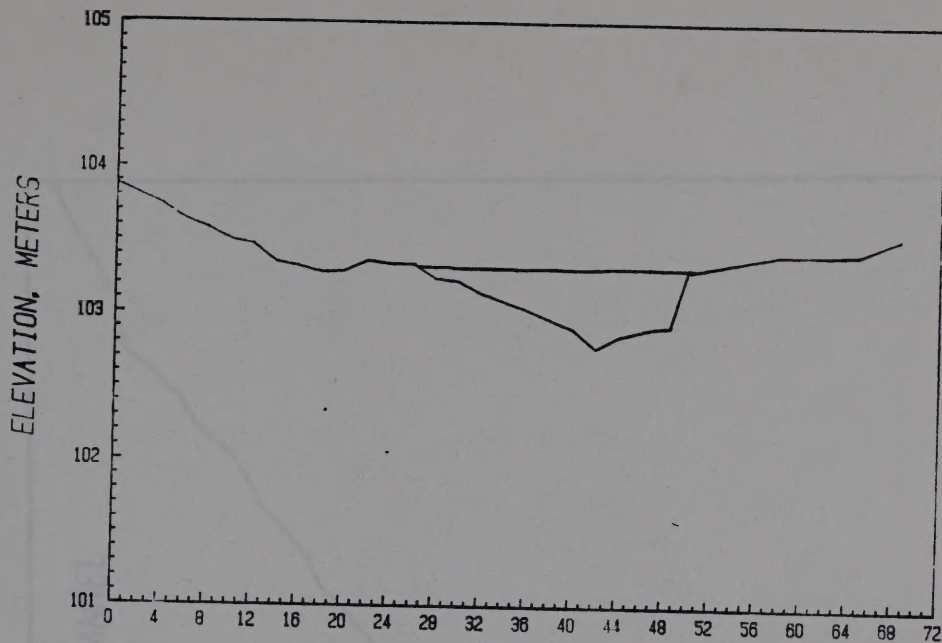
DISTANCE, FT., FROM RIGHT BANK, XSEC. 4



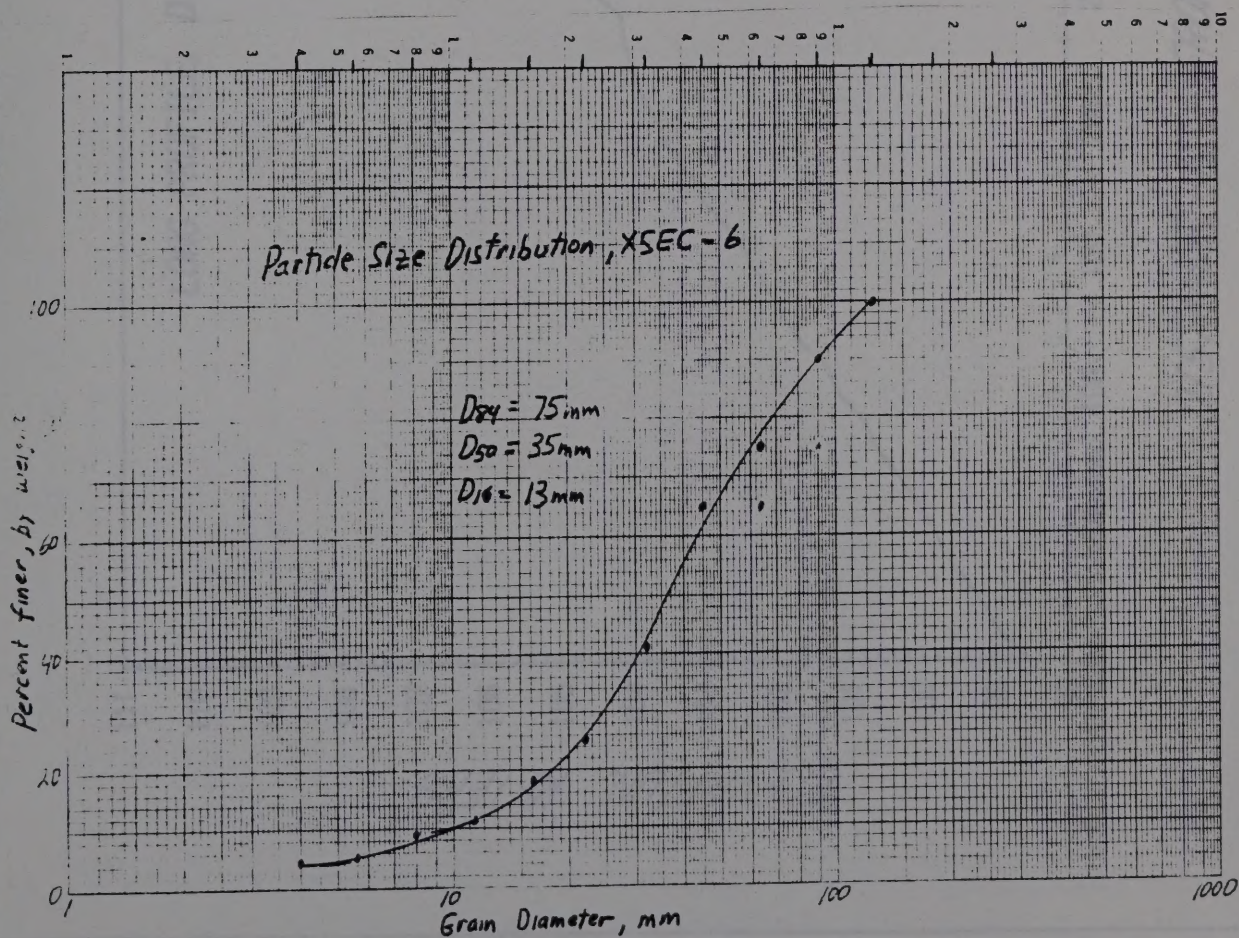


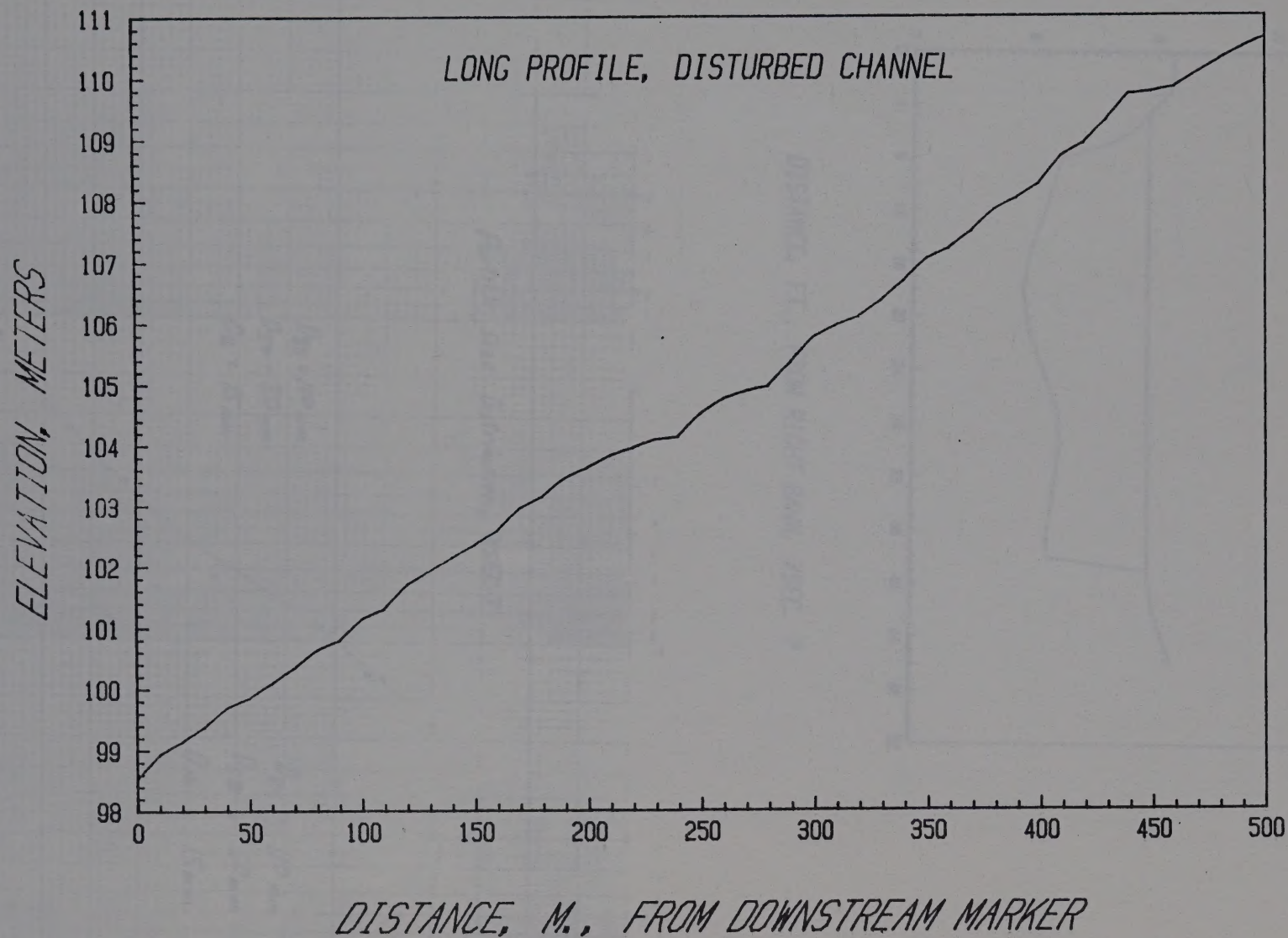
DISTANCE, FT., FROM RIGHT BANK, XSEC. 5

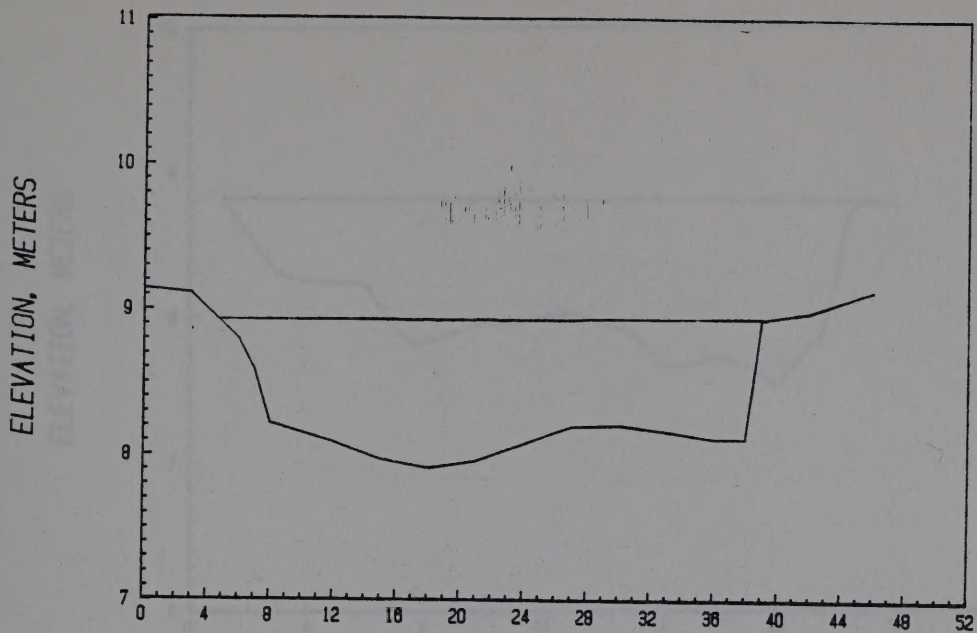




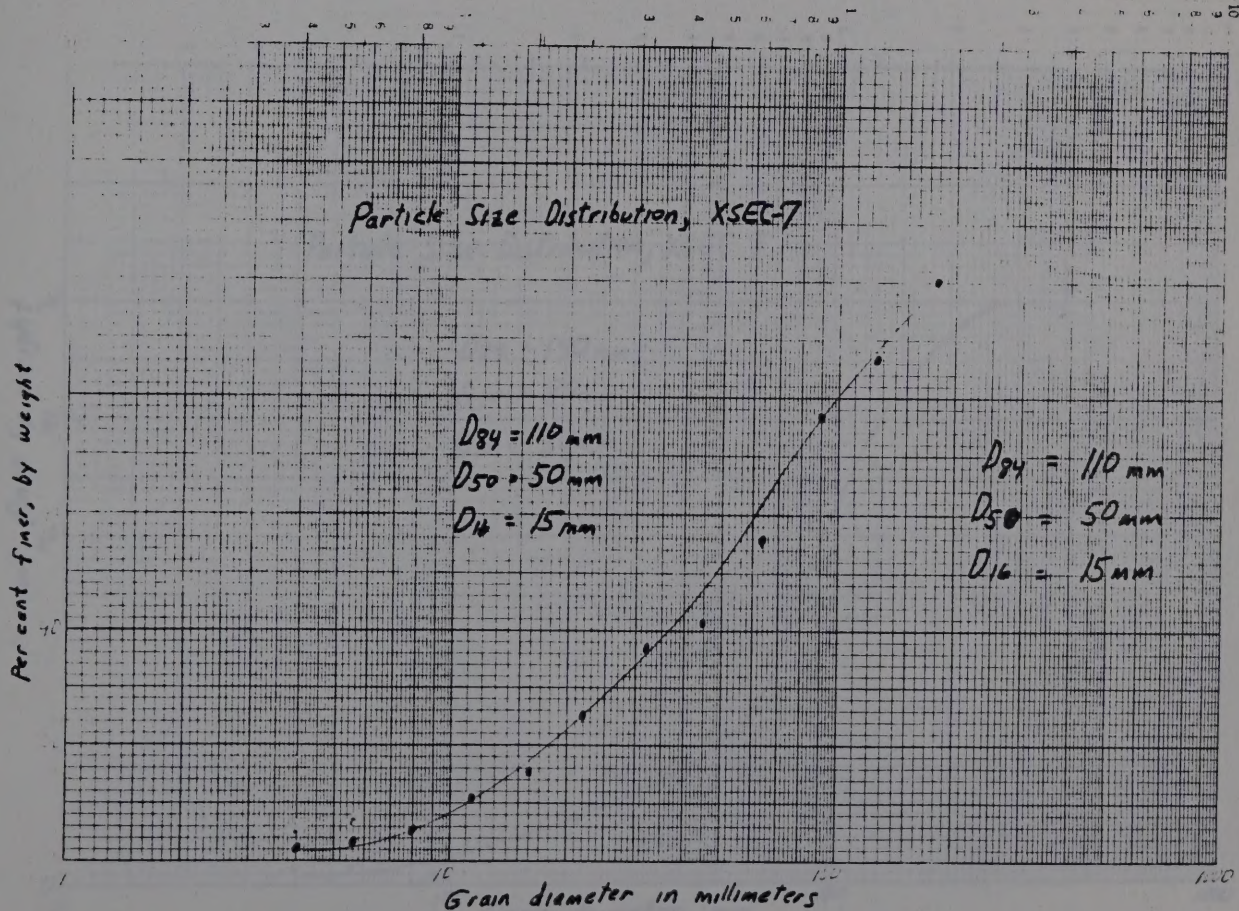
DISTANCE, FT., FROM RIGHT BANK, XSEC. 6

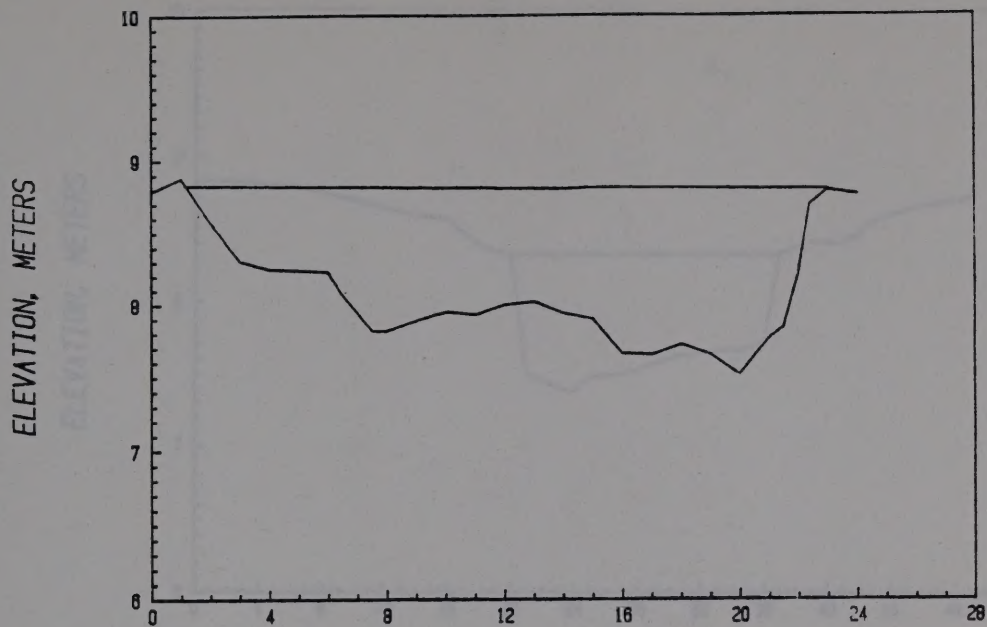




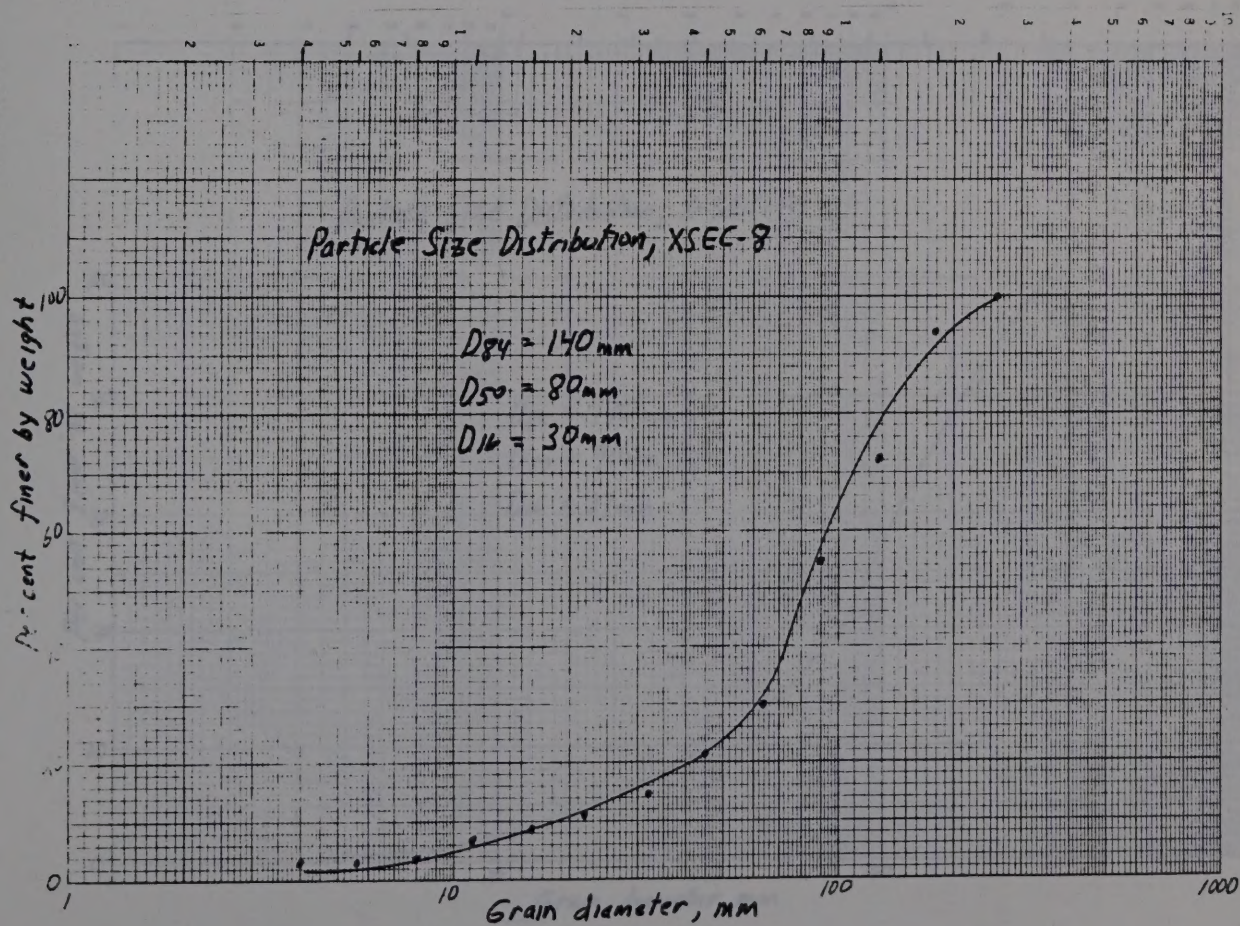


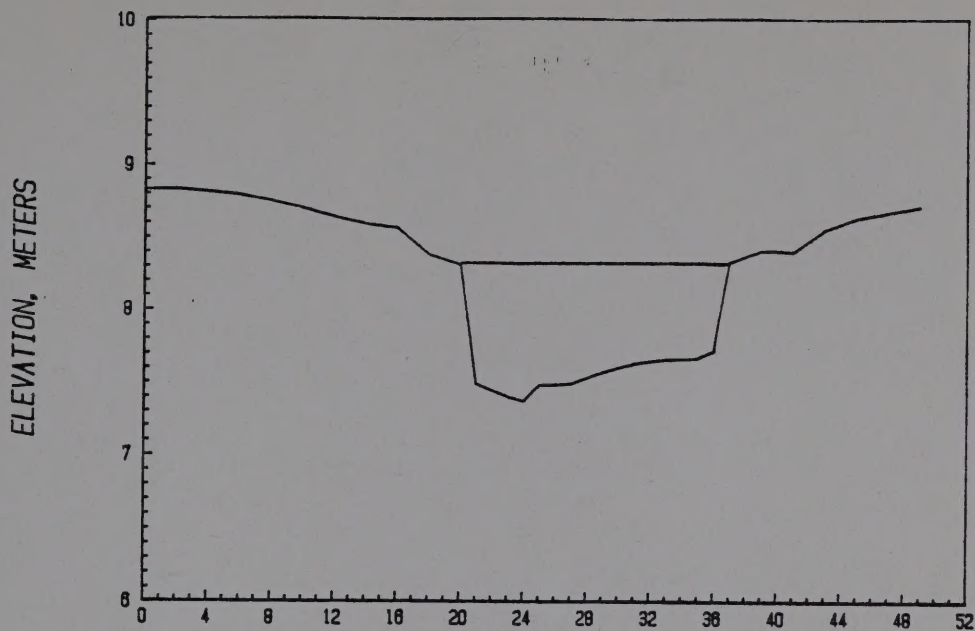
DISTANCE, FT., FROM RIGHT BANK, XSEC. 7



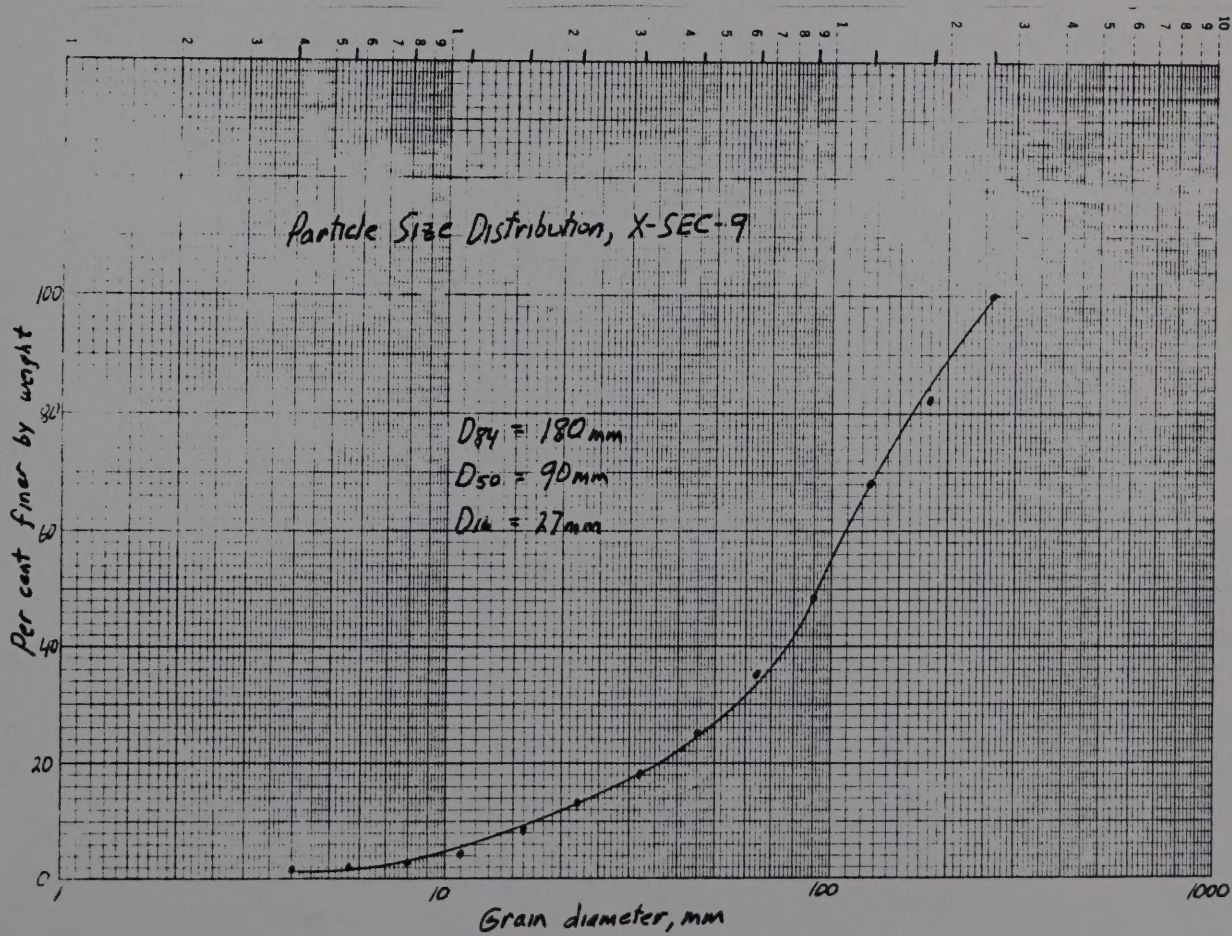


DISTANCE, M., FROM RIGHT BANK, XSEC. 8





DISTANCE, FT., FROM RIGHT BANK, XSEC. 9



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